

APPENDIX A:

Diesel PM Emissions from Eighteen Major California Railyards

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Diesel PM Emissions from Eighteen Major California Railyards (tons per year)

Railyard	Locomotive	Cargo Handling Equipment	On-Road Trucks	Others (Off-road, TRUs, Stationary, etc.)	Total [§]
South Coast Air Quality Management District					
BNSF Hobart	5.9	4.2	10.1	3.7	23.9
UP ICTF/Dolores	9.8	4.4	7.5	2.0	23.7
BNSF San Bernardino	10.6	3.7	4.4	3.4	22.0
UP Colton	16.3	N/A	0.2	0.05	16.5
UP Commerce	4.9	4.8	2.0	0.4	12.1
UP City of Industry	5.9	2.8	2.0	0.3	10.9
UP LATC	3.2	2.7	1.0	0.5	7.3
UP Mira Loma	4.4	N/A	0.2	0.2	4.9
BNSF Commerce Eastern	0.6	0.4	1.1	1.0	3.1
BNSF Sheila	2.2	N/A	N/A	0.4	2.7
BNSF Watson	1.9	N/A	<0.01	0.04	1.9
Bay Area Air Quality Management District					
UP Oakland	3.9	2.0	1.9	3.4	11.2
BNSF Richmond	3.3	0.3	0.5	0.6	4.7
San Joaquin Valley Unified Air Pollution Control District					
UP Stockton	6.5	N/A	0.2	0.2	6.9
BNSF Stockton	3.6	N/A	N/A	0.02	3.6
San Diego Air Pollution Control District					
BNSF San Diego	1.6	N/A	0.007	0.04	1.7
Mojave Desert Air Quality Management District					
BNSF Barstow	27.1	0.03	0.04	0.75	27.9
Placer County Air District/Sac Metro AQMD					
UP Roseville	25.1	N/A	N/A	N/A	25.1
STATEWIDE RY TOTAL	136.8	25.33	31.15	17.0	210.1[§]
<i>Statewide RY Percent</i>	<i>65 percent</i>	<i>12 percent</i>	<i>15 percent</i>	<i>8 percent</i>	<i>100 percent</i>

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Diesel PM Emissions from 18 Major Railyards Summarized By Source Category

18 Major Railyards	Diesel PM Emissions (tons per year)	Percent of Railyard Diesel PM Emissions
Locomotives	137	65%
- Line Haul	65	48%
- Switch	57	42%
- Service/Testing	15	10%
Diesel Trucks	31	15%
Cargo Equipment	25	12%
TRUs/Other	17	8%
Total	210	100%

Estimated Railyard Diesel PM Emissions and Reductions from 2005 to 2020 (tons per year)

YEAR	TOTAL*	Percent Reduction from 2005	Line Haul Locomotives**	Switch Locomotives***	Service/ Test Locomotives	HDD Trucks	Cargo (CHE)	TRUs	Other (Stationary)
2005	210	-	65	57	15	31	25	15	2
2010	105	50%	33	29	13	6	13	9	2
2015	74	65%	31	13	10	5	9	5	1
2020	42	80%	17	6	7	4	5	2	1

* Assumes an average of 80 percent diesel PM emission reductions for 18 classification and intermodal railyards.

** Assumes full implementation of 1998 and 2008 U.S. EPA rulemakings, 1998 and 2005 ARB/Railroad Agreements, CARB or ULSD for all California locomotives, and beginning of introduction of Tier 4 locomotives nationally between 2015 and 2020.

*** Assumes statewide replacement with advanced technology switch locomotives at 90% PM control with use of CARB diesel.

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The Table below provides an estimate of diesel PM emissions and reductions for 8 railyards through 2020. These estimates are based on the draft UP and BNSF railyard mitigation plans submitted to date. The estimates are also based on commitments UP and BNSF have made since the release of the draft railyard mitigation plans.

Estimated Railyard Diesel PM Emissions and Reductions for Eight Railyards (tons per year)

Railyard	2005	2010	2015	2020	Additional Reductions ¹	Goals for 2020 ²
BNSF Hobart (MICR: 500 ⁴)	24.7 Reduction	9.5 61%	6.4 74%	4.2 83%	3.2 87%	1.3 95%
UP Commerce (MICR: 500 ⁴)	11.2 – 9.6 Reduction	5.4 52%	3.7 67%	2.9 (2.3) ³ 74% (80%)	1.7 (1.1) ³ 85% (90%)	0.6 95%
BNSF Commerce/ Eastern (MICR: 100 ⁴)	3.1 – 2.7 Reduction	1.16 62%	0.83 73%	0.65 79%	N/A N/A	0.65 79%
BNSF Sheila (MICR: 40 ⁴)	2.7 Reduction	N/A N/A	N/A N/A	N/A N/A	N/A N/A	1.7 37%
BNSF San Bernardino (MICR: 2,500 ⁴)	22.0 - 22.4 Reduction	12.0 46%	8.2 63%	5.4 76%	4.1 82%	1.9 91%
UP ICTF/Dolores (MICR: 800 ⁴)	20.3 Reduction	11.8 42%	6.5 68%	5.4 73%	3.2 84%	0.6 97%
UP Oakland (MICR: 460 ⁴)	11.2-9.9 Reduction	5.9 57%	4.0 64%	3.2 71%	2.0 82%	0.5 95%
UP Industry (MICR: 450 ⁴)	10.9-9.8 Reduction	4.8 56%	3.3 70%	2.6 75%	N/A N/A	0.55 95%

1. Achieved through underestimated benefits of ARB regulations (CHE, Trucks) and additional voluntary options (e.g., replacement of switch locomotives with gen-sets, accelerated fleet turnover of Cargo Handling Equipment, etc.).
2. Primarily achieved through additional locomotive emissions reductions and site specific options (e.g., trees, walls, etc.).
3. Revised CHE and Truck emissions reductions.
4. 2005 MICR estimate.

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APPENDIX B:

U.S EPA Locomotive Emission Standards

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In 1998, U.S. EPA established national emission standards for 1973 and later locomotives (see Table below). The applicability of these emission standards is based on the original manufacture date for the locomotive, and follows a tiered system. The most stringent existing standards (Tier 2) provided a significant reduction in locomotive emissions.

1998 U.S. EPA Locomotive NOx and PM Emission Standards

Type	Tier	Date of Original Manufacture	NOx Standard (g/bhp-hr)	Percent Control When Engine is New or Remanufactured *	PM Standard (g/bhp-hr)	Percent Control When Engine is New or Remanufactured *
Line-haul locomotives	Tier 0 **	1973-2001	9.5	30 percent	0.6	N/A
	Tier 1	2002-2004	7.4	45 percent	0.45	N/A
	Tier 2	2005 and later	5.5	60 percent	0.20	59 percent
Switcher locomotives	Tier 0 **	1973 - 2001	14.0	29 percent	0.72	N/A
	Tier 1	2002 - 2004	11.0	44 percent	0.54	N/A
	Tier 2	2005 and later	8.1	59 percent	0.24	59 percent

* Relative to pre-Tier 0 locomotives.

** New Tier 0 locomotives model years 2000 and 2001. Also, existing 1973 to 1999 model year locomotives remanufactured to meet Tier 0 locomotive emissions standards.

In 2008, U.S. EPA released a new federal locomotive rulemaking. A particular emphasis was placed on reducing PM emissions from existing locomotives and the introduction of new Tier 4 locomotives by 2015. Tier 4 locomotives with DPF and SCR are expected to reduce locomotive emissions, beyond Tier 2 NOx and PM emissions levels, by up to 76 and 85 percent, respectively. See next two tables for NOx and PM standards.

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2008 U.S. EPA Locomotive NOx Emission Standards

Type	Tier	Date of Original Manufacture	Existing NOx Standard (g/bhp-hr)	New NOx Standard New and Remanufactured (g/bhp-hr)	Percent Control When Engine is New or Remanufactured*
Line-haul locomotives	<i>Uncontrolled</i>	<i>Pre-1973</i>	13.5	8.0 or 7.4	41 percent or 45 percent
	<i>Tier 0 *</i>	1973 – 2001	9.5	8.0 or 7.4	16 percent or 22 percent
	Tier 1	2002 – 2004	7.4	7.4	0 percent
	Tier 2	2005-2012	5.5	5.5	0 percent
	Tier 3	2012	N/A	5.5	0 percent
	<i>Tier 4</i>	2015-2017	N/A	1.3	76 percent (vs. Tier 2)
Switcher locomotives	<i>Uncontrolled</i>	<i>Pre-1973</i>	17.4	11.8	40 percent
	<i>Tier 0</i>	1973 – 2001	14.0	11.8	16 percent
	Tier 1	2002 – 2004	11.0	11.0	0 percent
	Tier 2	2005-2011	8.1	8.1	0 percent
	<i>Tier 3</i>	2011	N/A	5.0	48 percent (vs. Tier 2)
	<i>Tier 4</i>	2015	N/A	1.3	84 percent (vs. Tier 2)

Note: In most cases, gen-set and electric hybrid switchers have been U.S. EPA NOx emissions certified at levels below 3.0 g/bhphr, without aftertreatment. The LNG units have certification test data below 3.0.

* In most cases, except for Tier 4, as compared to pre-Tier 0 emissions levels.

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2008 U.S. EPA Locomotive PM Emission Standards

Type	Tier	Date of Original Manufacture	Existing PM Standards (g/bhp-hr)	New PM Standards Remanufactured or New (g/bhp-hr)	Percent Control When Engine is New or Remanufactured*
Line-haul locomotives	<i>Uncontrolled</i>	<i>Pre-1973</i>	<i>0.34</i>	<i>0.22</i>	<i>35 percent</i>
	<i>Tier 0</i>	<i>1973 - 2001</i>	<i>0.60</i>	<i>0.22</i>	<i>63 percent</i>
	<i>Tier 1</i>	<i>2002 - 2004</i>	<i>0.45</i>	<i>0.22</i>	<i>49 percent</i>
	<i>Tier 2</i>	<i>2005-2011</i>	<i>0.20</i>	<i>0.10</i>	<i>50 percent</i>
	<i>Tier 3</i>	<i>2012</i>	<i>N/A</i>	<i>0.10</i>	<i>50 percent (vs. Tier 2)</i>
	<i>Tier 4</i>	<i>2014</i>	<i>N/A</i>	<i>0.03</i>	<i>85 percent (vs. Tier 2)</i>
Switcher locomotives	<i>Tier 0</i>	<i>1973 - 2001</i>	<i>0.72</i>	<i>0.26</i>	<i>64 percent</i>
	<i>Tier 1</i>	<i>2002 - 2004</i>	<i>0.54</i>	<i>0.26</i>	<i>48 percent</i>
	<i>Tier 2</i>	<i>2005-2010</i>	<i>0.24</i>	<i>0.13</i>	<i>54 percent</i>
	<i>Tier 3</i>	<i>2011</i>	<i>N/A</i>	<i>0.10</i>	<i>58 percent (vs. Tier 2)</i>
	<i>Tier 4</i>	<i>2015</i>	<i>N/A</i>	<i>0.03</i>	<i>87 percent (vs. Tier 2)</i>

Note: In most cases, gen-set, electric hybrid, and LNG switchers have certification test data at levels below 0.15 g/bhphr, without aftertreatment.

* In most cases, except for Tier 4, as compared to pre-Tier 0 emissions levels.

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APPENDIX C:

Current Status of Aftertreatment for Existing Locomotives

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CURRENT STATUS OF AFTERTREATMENT FOR EXISTING LOCOMOTIVES

We have been working with U.S. EPA, SCAQMD, and UP and BNSF to develop and demonstrate aftertreatment for existing (pre-Tier 0 through Tier 2) interstate line haul, medium horsepower (MHP), and switch locomotives. In this section we will examine the status of the locomotive aftertreatment efforts to date.

A. Background on Aftertreatment

Two aftertreatment options that could be retrofitted to existing locomotives to reduce PM emissions are diesel particulate filters (DPFs) and diesel oxidation catalysts (DOCs). Selective catalytic reduction (SCR) could be retrofitted to existing locomotives to reduce NO_x emissions. A key question to be addressed is whether the filters can maintain the anticipated level of control and necessary durability over time, particularly in interstate line haul operations. In addition, it is critical that aftertreatment adversely affect engine exhaust flows and combustion efficiencies and can fit into the limited areas available within a locomotive carbody space. The latter is critical due to considerations of locomotives being able to travel through tunnels across the nation. Finally, after the aftertreatment has been demonstrated successfully on a single locomotive, the ARB verification process will need to be completed. The final step would be for a manufacturer to make the ARB verified aftertreatment commercially available.

1. *Diesel Oxidation Catalysts (DOCs)*

Diesel oxidation catalysts (DOCs) use a catalyst material and oxygen in the air to trigger a chemical reaction that converts a portion of diesel PM and ROG into carbon dioxide and water. These catalysts have been shown to reduce diesel PM emissions by 20 to 50 percent and ROG emissions by up to 30 percent. While diesel particulate filters typically need a low-sulfur content fuel to operate effectively, DOCs are tolerant of higher fuel sulfur contents. DOCs can be effective in controlling soluble organic fraction (SOF – oil and diesel fuel combustion related) emissions from locomotives, but is not as effective as DPFs in controlling fine particulates.

A DOC may be the first line control system needed to enhance the effectiveness of both a DPF and an SCR on locomotives. A DOC can reduce large particles to enhance the efficiency of a DPF and to reduce carbon build up on a DPF's walls. A DOC can also reduce carbon build up for a SCR and increase NO₂ generation to improve SCR control efficiencies.

2. *Diesel Particulate Filters (DPFs)*

DPFs contain a semi-porous material that permits gases in the exhaust to pass through while trapping the diesel soot, with a PM control efficiency of 85 percent or more. They have been successfully demonstrated in the laboratory and demonstrated on two U.S. switch locomotives (UP and BNSF), where they reduced diesel PM emissions by up to about 80 percent. A concern with the use of DPFs is the high levels of the soluble

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organic fraction, lube oil, and diesel fuel that are emitted from locomotives and that can potentially plug a DPF, thereby requiring extensive cleaning and maintenance.

A passive DPF system relies on locomotive exhaust temperatures to burn away ash and carbon buildup on the DPF. However, locomotives can operate a substantial part of the time in lower power settings, where locomotive exhaust temperatures may not be high enough to burn off carbon build up on DPFs. A regenerative DPF system periodically uses diesel fuel ignition to burn away DPF ash and carbon buildup. As a result, there can be small amounts of diesel PM emissions with the regenerative system. With locomotives, there may be the potential for a hybrid DPF system where passive (for use on higher power settings) and regenerative (for use on locomotive lower power settings) systems are combined.

2. *Selective Catalytic Reduction (SCR)*

Another control option for existing locomotives is to retrofit selective catalytic reduction (SCR). SCR is a means of converting NO_x with the aid of a catalyst into diatomic nitrogen, N₂, and water, H₂O. A gaseous reductant, typically anhydrous ammonia, aqueous ammonia, or urea, is added to a stream of flue or exhaust gas and is absorbed onto a catalyst. CO₂ is a reaction product when urea is used as the reductant. SCR catalysts are manufactured from various ceramic materials used as a carrier, such as titanium oxide, and active catalytic components are usually either oxides of base metals (such as vanadium and tungsten), zeolites, and various precious metals. SCR has been used on stationary sources (e.g., boilers) and has been shown to reduce NO_x emissions by 70 to 95 percent.

One of the key challenges with SCR on an interstate line haul locomotive is being able to design a system that precisely meters urea to approach a one to one conversion ratio between urea to NO_x and to minimize potentially toxic emissions from ammonia slip. Further, the lower locomotive engine exhaust temperatures in lower notch settings (i.e., idle to Notch 3) significantly reduce the levels of control from SCR.

B. *Demonstration of DPFs on a Gen-Set Switch Locomotive*

Brookville Equipment Company recently installed a passive DPF system on a prototype three engine gen-set switch locomotive built with three Cummins QSK19 Tier 3 nonroad engines. Brookville employed a passive DPF system that relied on locomotive exhaust temperatures to burn away ash and carbon buildup on the DPF. During field testing, Brookville began to experience ongoing ash buildup and cleaning problems with the passive DPF system. As the DPF is not required by any regulation, Brookville chose for the time being to remove the passive DPF system from the prototype gen-set switch locomotive during field testing.

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C. Demonstration of Experimental DPFs on Older Switch Locomotives

ARB and the UP and BNSF entered into the California Emissions Program (CEP) in 2001. The two railroads funded this effort with \$5 million, and as of April 2008 about \$4 million or more has been expended. The CEP's primary objective was to demonstrate the use of DPFs on older switch locomotives. UP and BNSF each provided an older (both over 25 years old) switch locomotive of about 1,500 horsepower for this program.

After five years of research and bench testing, the UP and BNSF switch locomotives were retrofitted with very large DPFs (about piano size – 1,100 pounds) in front of the cabs of UPY 1378 and BNSF 3703. Baseline emission testing indicates that these switchers can provide up to an 80 percent reduction in particulate matter and 30 percent reduction in hydrocarbon emissions.

UPY 1378 was released into demonstration service in December 2006 to the UP Oakland yard, and then recently transferred to the UP Roseville yard. UPY 1378 has been operating over the past year with only minor mechanical and aftertreatment adjustments. BNSF 3703 was retrofitted with the DPF in late 2006, but for nearly two year had not been able to leave the Southwest Research Institute (SWRI) facility in San Antonio, Texas due to ongoing technical challenges in getting the DPF system to work properly with the locomotive. In 2008, BNSF 3703 arrived in Southern California for demonstration testing.

An important consideration with DPF retrofits on switch locomotives is the recent advances in switch locomotive technology (i.e., gen-set and electric hybrid) since the CEP program was initiated over 7 years ago. Gen-set and electric hybrid switch locomotives can provide up to a 90 percent reduction in both particulate matter and NO_x emissions. These switch locomotives also significantly reduce diesel fuel consumption by 20 to 40 percent.

Due to the DPF and engine rebuild (Tier 0) capital costs (\$300,000 to \$500,000 or more) and ongoing maintenance costs of DPFs, the new advanced technology switch locomotives may make the retrofitting of older (20-50 year old) switch locomotives with DPFs less cost competitive with the new switch technologies. In California, an important question would be whether to invest limited capital into aftertreatment retrofits of 25 to 50 year old switch locomotives, or whether to purchase new gen-set switch locomotives instead. The gen-set engines provide ongoing fuel savings and these engines can easily be changed (in a few days) for upgrades to future nonroad engines with even more stringent emission standards.

D. Demonstration of an Experimental Diesel Oxidation Catalyst (DOC) on an Older Freight Line Haul Locomotive

U.S. EPA and UP initiated a demonstration program, in April 2006, on an existing freight line haul locomotive (UP 2368). UP 2368 is an EMD SD60M model interstate freight line haul locomotive built in 1989 and powered by an EMD 710 - 16 cylinder engine. UP

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2368's engine was rebuilt from uncontrolled levels to a Tier 0 level and then retrofitted with a Miratech DOC. UP 2368 was then placed into service in California in October 2006.

UP 2368 baseline emission testing indicated that the DOC could reduce larger particles (e.g., soluble organic fraction) in particulate matter by up to 50 percent. However, during in-field demonstrations in 2007, there were three separate incidents of DOC aftertreatment and DOC support structure failures. The most recent failure resulted in the breakdown of catalysts that broke away from the DOC and flew up into the turbocharger. Fortunately, this failure was caught early enough to prevent any turbocharger or engine damage. Generally, these three DOC related failures have been attributed to locomotive vibration and the large two-stroke medium speed EMD engine with extreme and intermittent exhaust pulsations. Miratech worked on a new DOC design and support frames to protect the integrity of the DOC catalysts under locomotive vibration and stresses, and UP 2368 was returned to service in Southern California in May 2008. UP 2368 has performed successfully for over the past six months, and the same DOCs used on UP 2368 have been retrofitted on two Canadian passenger locomotives.

E. SwRI Bench Test of a Compact SCR on a Locomotive Engine

ARB recently funded a \$200,000 research effort with the SwRI. This research consisted of a bench test program of a compact SCR system offered by Engine Fuel and Emissions Engineering, Inc. (EF&EE) (via Haldor Topsoe – a Danish Catalyst Company) and funded by the SCAQMD for use on a MHP Metrolink passenger locomotives. The SWRI bench tests were conducted on an EMD 710 – 12 cylinder engine, which is the same engine family commonly used on pre-2000 freight line haul locomotives (~75 percent), passenger locomotives (most in California), and some marine vessels. The EMD 710 engine was retrofitted with the compact SCR device for performance and emission testing. During the performance testing, significant issues occurred with the SCR system's ability to dose the urea properly. Part of this urea dosing imbalance was caused by the un-uniform engine exhaust flows of the EMD 710 engine and the challenge for the compact SCR system to be able to adjust urea dosing precisely to the engine exhaust fluctuations. This imbalance in the dosing of the urea resulted in large amounts of ammonia slip and dried ammonia crystals deposited throughout the engine. EF&EE is currently working to redesign the compact SCR and urea dosing system to try to address these issues. SWRI completed the report for this research effort in March 2008.

Summary of the Status of Locomotive Aftertreatment

As of November 2008, ARB staff has not verified any locomotive aftertreatment system. Staff is optimistic that candidates for locomotive aftertreatment systems will be submitted for ARB verification sometime in 2009.

APPENDIX D:

**AAR publication on
“Railroad Service” and “Freight Railroads Operating”
in California**

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Railroad Service in California

2006

Railroad Service and Employment

Facilities	Number of Freight Railroads	24
	Miles Operated (Excluding Trackage Rights)	5,352
Traffic	Total Carloads of Freight Carried	7,578,456
	Total Tons of Freight Carried	177,907,810
Employment and Earnings	Rail Employees Living in State	15,268
	Freight Employees Only	10,478
	Total Wages of Rail Employees	\$1,042,945,000
	Freight Employees Only	\$726,479,000
	Average Per Freight Rail Employee:	
	Wages	\$69,300
	Fringe Benefits	\$26,900
Railroad Retirement	Railroad Retirement Beneficiaries	29,196
	Railroad Retirement Benefits Paid	\$445,149,000

Freight Railroad Traffic in California

Tons Originated 2006			Tons Terminated 2006		
	Tons	%		Tons	%
Mixed Freight*	37,794,104	54%	Mixed Freight*	28,407,880	26%
Food Products	6,250,236	9	Farm Products	13,696,924	12
Primary Metal Products	3,727,429	5	Food Products	11,616,124	11
Glass & Stone Products	3,697,956	5	Chemicals	10,977,633	10
Chemicals	3,616,449	5	Lumber & Wood Prod.	6,843,232	6
All Other	14,980,922	21	All Other	38,575,378	35
Total	70,067,096	100%	Total	110,117,171	100%

*Predominantly Intermodal

Railroad Map of California



Rail network based upon 2006 National Transportation Atlas Database published by the U.S. DOT, Bureau of Transportation Statistics.

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June 2008

Freight Railroads Operating in California

2006

	Miles of Railroad Operated in California
Class I Railroads	
BNSF Railway Company	2,130
Union Pacific Railroad Co.	3,358
	<hr/> 5,488
Regional Railroads	
Central Oregon & Pacific Railroad	52
San Joaquin Valley Railroad Co.	351
	<hr/> 403
Local Railroads	
Arizona & California Railroad Co.	133
Carrizo Gorge Railway Inc.	80
McCloud Railway Co.	100
Modoc Northern Railroad Company	96
San Diego & Imperial Valley Railroad	41
Santa Maria Valley Railroad	14
Sierra Northern Railway	99
Stockton Terminal & Eastern Railroad	30
Trona Railway Co.	31
Ventura County Railroad Company	13
West Isle Line, Inc.	5
Yreka Western Railroad	12
	<hr/> 654
Switching & Terminal Railroads	
California Northern Railroad	247
Modesto & Empire Traction Co.	34
Napa Valley Railroad Co.	21
Oakland Terminal Railway	6
Pacific Harbor Line, Inc.	21
Quincy Railroad	3
Richmond Pacific Railroad Corp.	10
Santa Cruz, Big Trees & Pacific Railway	10
	<hr/> 352

California Totals	Number of Freight Railroads	Miles Operated	
		Excluding Trackage Rights	Including Trackage Rights
Class I	2	3,990	5,488
Regional	2	403	403
Local	12	640	654
Switching & Terminal	8	319	352
Total	24	5,352	6,897



Rail network based upon 2006 National Transportation Atlas Database published by the U.S. DOT, Bureau of Transportation Statistics.

Class I Railroad - As defined by the Surface Transportation Board, a railroad with 2006 operating revenues of at least \$346.7 million.
Regional Railroad - A non-Class I line-haul railroad operating 350 or more miles of road and/or with revenues of at least \$40 million.
Local Railroad - A railroad which is neither a Class I nor a Regional Railroad and is engaged primarily in line-haul service.
Switching & Terminal Railroad - A non-Class I railroad engaged primarily in switching and/or terminal services for other railroads.
Note: Railroads operating are as of December 31, 2006. Some mileage figures may be estimated.

APPENDIX E:
Calculations for Switch Locomotives

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Calculations of Switch Locomotive NOx and PM Emissions:

(Source: U.S. EPA Fact Sheet – Emission Factors for Locomotives – U.S. EPA420-F-97-051 – December 1997)

<http://www.U.S. EPA.gov/otaq/regs/nonroad/locomotv/frm/42097051.pdf>

Switch Locomotive Emission Factors (EF)

(g/bhp-hr)	NOx EF	PM EF
Pre Tier 0	17.4	0.72
Tier 0	14.0	0.72
Tier 0+	11.8	0.26
ULESL	3.0	0.10
Tier 3	3.0	0.10
Tier 4	1.3	0.03
Tier 4 Nonroad	0.3	0.01

Conversion Factors

bhp-hr/gallon
20.8

tons/g
1.10E-06

UP and BNSF Switch Locomotive Fleet Composition (2008)

Switchers	# Locos	Pre Tier 0	Tier 0	ULESL
Statewide	244	103	49	92
South Coast	139	34	29	76
Rest of State	105	69	20	16

Other Key Assumptions:

Pre-Tier 0 and Tier 0 switch locomotives are assumed to consume 50,000 gallons of diesel fuel per year. ULESLs, Tier 3, and Tier 4 switch locomotives are assumed to consume 40,000 gallons of diesel fuel per year due to 20% reduction with ULESLs: gen-sets, electric hybrids, and LNGs.

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Replace 152 older UP/BNSF switchers with new ULESL switch locomotives

<i>Emission Reduction (TPD)</i>	NOx	PM
Statewide	6.6	0.30
South Coast	2.8	0.14
Rest of State	3.8	0.16

NOx:

NOx Baseline Emissions – $17.4 \text{ g/bhp-hr} \times 20.8 = 362 \text{ grams/gallon}$.

103 pre-Tier 0 UP and BNSF Switch Locomotives

$50,000 \text{ gallons/yr} \times 362 \text{ grams/gallon} = 18,100,000 \text{ grams/yr}$
 $18,100,000 \text{ grams/yr} / 454 \text{ g/lb} = 39,867.84 \text{ lbs/yr}$
 $39,867.84 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 19.93 \text{ tons/yr}$
 $19.93 \text{ tons/yr} / 365 \text{ days/yr} = 0.0546 \text{ tons/day}$
NOx x 103 pre-Tier 0 switchers = 5.625 tons/day NOx emissions.

NOx Baseline Emissions – $14.0 \text{ g/bhp-hr} \times 20.8 = 291 \text{ grams/gallon}$.

49 Tier 0 UP and BNSF Switch Locomotives

$50,000 \text{ gallons/yr} \times 291 \text{ grams/gallon} = 14,550,000 \text{ grams/yr}$
 $14,550,000 \text{ grams/yr} / 454 \text{ g/lb} = 32,048.46 \text{ lbs/yr}$
 $32,048.46 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 16.0 \text{ tons/yr}$
 $16.0 \text{ tons/yr} / 365 \text{ days/yr} = 0.0439 \text{ tons/day}$
NOx x 49 Tier 0 switch locomotives = 2.15 tons/day NOx emissions.

103 pre-Tier 0 UP/BNSF switch locomotives + 49 Tier 0 UP/BNSF switch locomotives =

(5.625 tons/day) + (2.15 tons/day) = 7.776 tons/day NOx or 7.8 tons/day.

NOx baseline emissions for 152 older UP/BNSF switchers= 7.8 tons/day.

NOx Control Emissions – $3.0 \text{ g/bhp-hr} \times 20.8 = 62 \text{ grams/gallon}$.

152 ULESL UP and BNSF Switch Locomotives (20% Diesel Fuel Reduction)

$40,000 \text{ gallons/year} \times 62 \text{ grams/gallon} = 2,480,000 \text{ grams/yr}$
 $2,480,000 \text{ grams/yr} / 454 \text{ g/lb} = 5,462.55 \text{ lbs/yr}$
 $5,462.55 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 2.73 \text{ tons/yr}$
 $2.73 \text{ tons/yr} / 365 \text{ days/yr} = 0.00748 \text{ tons/day}$
NOx x 152 ULESLs = 1.1374 tons/day **NOx controlled emissions or 1.14 tons/day NOx controlled.**

NOx baseline emissions (7.776 tons/day) – NOx control emissions (1.1374 tons/day) = 6.6386 tons/day
NOx reduced or 6.64 or **6.6 tons/day NOx reduced.**

PM:

PM Baseline Emissions – $0.72 \text{ g/bhp-hr} \times 20.8 = 15 \text{ grams/gallon}$.

152 pre-Tier 0 and Tier 0 UP and BNSF Switch Locomotives

$50,000 \text{ gallons/yr} \times 15 \text{ grams/gallon} = 750,000 \text{ grams/yr}$
 $750,000 \text{ grams/yr} / 454 \text{ g/lb} = 1,651.98 \text{ lbs/yr}$
 $1,651.98 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 0.826 \text{ tons/yr}$
 $0.826 \text{ tons/yr} / 365 \text{ days/yr} = 0.002263 \text{ tons/day}$
PM x 152 pre-Tier and Tier 0 switchers = **0.344 tons/day PM baseline emissions.**

PM Control Emissions – $0.1 \text{ g/bhp-hr} \times 20.8 = 2 \text{ grams/gallon}$.

152 ULESL UP and BNSF Switch Locomotives (20% Diesel Fuel Reduction)

$40,000 \text{ gallons/year} \times 2 \text{ grams/gallon} = 80,000 \text{ grams/yr}$
 $80,000 \text{ grams/yr} / 454 \text{ g/lb} = 176.21 \text{ lbs/yr}$
 $176.21 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 0.088 \text{ tons/yr}$
 $0.088 \text{ tons/yr} / 365 \text{ days/yr} = 0.00024 \text{ tons/day}$
PM x 152 ULESLs = 0.03669 tons/day PM controlled emissions or **0.037 tons/day PM controlled.**

PM baseline emissions (0.344 tons/day) – PM control emissions (0.037 tons/day) = 0.307 tons/day PM reduced or 0.31 or **0.3 tons/day PM reduced.**

Cost-effectiveness:

1 year: $(6.6+0.3) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (1 \text{ yr}) = 50,370,000 \text{ lbs/yr}$.

10 years: $(6.6+0.3) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (10 \text{ yrs}) = 50,370,000 \text{ lbs/10 yrs}$.

20 years: $(6.4+0.3) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (20 \text{ yrs}) = 100,740,000 \text{ lbs/20 yrs}$.

Capital costs: $\$1,500,000 / 152 \text{ gen-set or ULESL locomotives} = \$228,000,000$

Cost-effectiveness= $\$228,000,000 / 100,740,000 \text{ lbs/20 yrs}$ to $\$228,000,000 / 50,370,000 \text{ lbs/10 yrs}$

= \$2.26/lb to \$4.53/lb or **(\$2-5/lb)**

PRELIMINARY DRAFT

DPF and SCR Retrofits of 244 UP/BNSF ULESLs Switch Locomotives:

<i>Emission Reduction(TPD)</i>	NOx	PM
Statewide	1.0	0.04
South Coast	0.6	0.02
Rest of State	0.4	0.02

NOx:

NOx Baseline Emissions – $3.0 \text{ g/bhp-hr} \times 20.8 = 62 \text{ grams/gallon}$.

244 UP and BNSF ULESLs (20% Diesel Fuel Reduction)

$40,000 \text{ gallons/yr} \times 62 \text{ grams/gallon} = 2,480,000 \text{ grams/yr}$
 $2,480,000 \text{ grams/yr} / 454 \text{ g/lb} = 5,462.55 \text{ lbs/yr}$
 $5,462.55 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 2.73 \text{ tons/yr}$
 $2.73 \text{ tons/yr} / 365 \text{ days/yr} = 0.00748 \text{ tons/day}$
NOx x 244 ULESLs = 1.825 tons/day NOx baseline emissions or
1.8 tons/day NOx baseline emissions.

NOx Control Emissions – $1.3 \text{ g/bhp-hr} \times 20.8 = 27 \text{ grams/gallon}$.

244 UP and BNSF ULESLs Retrofitted with SCR (20% Diesel Fuel Reduction)

$40,000 \text{ gallons/yr} \times 27 \text{ grams/gallon} = 1,080,000 \text{ g/yr}$
 $1,080,000 \text{ g/yr} / 454 \text{ g/lb} = 2,378.85 \text{ lbs/yr}$
 $2,378.85 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 1.1894 \text{ tons/yr}$
 $1.1894 \text{ tons/yr} / 365 \text{ days/yr} = 0.003258 \text{ tons/day}$
NOx x 244 ULESLs retrofitted with SCR =
0.795 tons/day NOx controlled.

NOx baseline emissions (1.8 tons/day) – NOx control emissions (0.795 tons/day) =

1.0 tons/day NOx reduced.

PM:

PM Baseline Emissions – $0.1 \text{ g/bhp-hr} \times 20.8 = 2 \text{ grams/gallon}$.

244 UP and BNSF ULESLs (20% Diesel Fuel Reduction)

$40,000 \text{ gallons/year} \times 2 \text{ grams/gallon} = 80,000 \text{ grams/yr}$
 $80,000 \text{ grams/yr} / 454 \text{ g/lb} = 176.21 \text{ lbs/yr}$
 $176.21 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 0.088 \text{ tons/yr}$
 $0.088 \text{ tons/yr} / 365 \text{ days/yr} = 0.00024 \text{ tons/day}$
PM x 244 ULESLs = 0.05856 tons/day PM baseline emissions or
0.059 tons/day PM baseline emissions.

PM Control Emissions – $0.03 \text{ g/bhp-hr} \times 20.8 = 0.624 \text{ grams/gallon}$.

244 UP and BNSF ULESLs Retrofitted with DPFs (20% Diesel Fuel Reduction)

$40,000 \text{ gallons/yr} \times 0.624 \text{ grams/gallon} = 24,960 \text{ g/yr}$
 $24,960 \text{ g/yr} / 454 \text{ g/lb} = 54.98 \text{ lbs/yr}$
 $54.98 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 0.0275 \text{ tons/yr}$
 $0.0275 \text{ tons/yr} / 365 \text{ days/yr} = 0.0000753 \text{ tons/day}$
PM x 244 ULESLs retrofitted with DPFs =
0.018 tons/day NOx control emissions

PM baseline emissions (0.059 tons/day) – PM control emissions (0.018 tons/day) = 0.041 tons/day PM reduced or **0.04 tons/day PM reduced.**

Cost-effectiveness:

1 year: $(1.0+0.04) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (1 \text{ yr}) = 759,200 \text{ lbs/yr}$.

10 years: $(1.0+0.04) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (10 \text{ yrs}) = 7,592,000 \text{ lbs/10 yrs}$.

20 years: $(1.0+0.04) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (20 \text{ yrs}) = 15,184,000 \text{ lbs/20 yrs}$.

Capital costs: $\$200,000 / \times 244 \text{ ULESL locomotives} = \$48,800,000$.

Cost-effectiveness = $\$ (48,800,000 / 7,592,000)$ to $\$ (48,800,000 / 15,184,000)$
= \$3.21/lb to \$6.43/lb or (\$3-7/lb)

PRELIMINARY DRAFT

Repower 244 ULESL switch locomotives, that had been retrofitted with DPF and SCR, with new Tier 4 nonroad engines

(Emissions Reductions beyond ULESL and DPF/SCR Retrofit)

Emission Reduction(TPD)	NOx	PM
Statewide	0.60	0.01
South Coast	0.35	0.007
Rest of State	0.25	0.005

NOx:

NOx Baseline Emissions – $1.3 \text{ g/bhp-hr} \times 20.8 = 27 \text{ grams/gallon}$.

244 UP and BNSF ULESLs Retrofitted with SCR (20% Diesel Fuel Reduction)

$40,000 \text{ gallons/yr} \times 27 \text{ grams/gallon} = 1,080,000 \text{ g/yr}/454 \text{ g/lb}=2,378.85 \text{ lbs/yr}/2,000 \text{ lbs/ton}=1.1894 \text{ tons/yr}/365 \text{ days/yr}=0.003258 \text{ tons/day}$ NOx x 244 ULESLs retrofitted with SCR =

0.795 tons/day NOx controlled.

NOx Control Emissions – $0.3 \text{ g/bhp-hr} \times 20.8 = 6.24 \text{ grams/gallon}$.

244 UP and BNSF ULESLs Tier 4 Nonroad Engines (20% Diesel Fuel Reduction)

$40,000 \text{ gallons/yr} \times 6.24 \text{ grams/gallon} = 249,600 \text{ grams/yr}/454 \text{ g/lb}=549.78 \text{ lbs/yr}/2,000 \text{ lbs/ton}=0.2749 \text{ tons/yr}/365 \text{ days/yr}=0.000753 \text{ tons/day}$ NOx x 244 ULESLs with Tier 4 Nonroad engines = 0.18376

tons/day NOx baseline emissions or **0.184 tons/day NOx control emissions.**

NOx baseline emissions (0.795 tons/day) – NOx control emissions (0.184 tons/day) =

0.61 tons/day NOx reduced.

PM:

PM Baseline Emissions – $0.03 \text{ g/bhp-hr} \times 20.8 = 0.624 \text{ grams/gallon}$.

244 UP and BNSF ULESLs Retrofitted with DPFs (20% Diesel Fuel Reduction)

$40,000 \text{ gallons/yr} \times 0.624 \text{ grams/gallon} = 24,960 \text{ g/yr}/454 \text{ g/lb}=54.98 \text{ lbs/yr}/2,000 \text{ lbs/ton}=0.0275 \text{ tons/yr}/365 \text{ days/yr}=0.0000753 \text{ tons/day}$ PM x 244 ULESLs retrofitted with DPFs =

0.018 tons/day NOx control emissions

PM Control Emissions – $0.01 \text{ g/bhp-hr} \times 20.8 = 0.208 \text{ grams/gallon}$.

244 UP and BNSF ULESLs with Tier 4 Nonroad Engines (20% Diesel Fuel Reduction)

$40,000 \text{ gallons/year} \times 0.208 \text{ grams/gallon} = 8,320 \text{ grams/yr}/454 \text{ g/lb}=18.33 \text{ lbs/yr}/2,000 \text{ lbs/ton}=0.0092 \text{ tons/yr}/365 \text{ days/yr}=0.000025 \text{ tons/day}$ PM x 244 ULESLs with Tier 4 Nonroad Engines =

0.006 tons/day PM baseline emissions.

PM baseline emissions (0.018 tons/day) – PM control emissions (0.006 tons/day) = 0.012 tons/day PM reduced or **0.01 tons/day PM reduced.**

Cost-effectiveness:

1 year: $(0.61+0.01) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (1 \text{ yr}) = 452,600 \text{ lbs/yr}$.

10 years: $(1.0+0.04) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (10 \text{ yrs}) = 4,526,000 \text{ lbs}/10 \text{ yrs}$.

20 years: $(1.0+0.04) \times (2000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (20 \text{ yrs}) = 9,052,000 \text{ lbs}/20 \text{ yrs}$.

Capital costs: $\$200,000/ \times 244 \text{ ULESL locomotives} = \$48,800,000$.

Cost-effectiveness = $\$(48,800,000/4,526,000) \text{ to } \$(48,800,000/9,052,000)$

= $\$10.78/\text{lb}$ to $\$5.39/\text{lb}$ or $(\$5.50\text{-}11/\text{lb})$

PRELIMINARY DRAFT

Remanufacture 152 older UP and BNSF switch locomotives to meet the U.S. EPA Tier 0 Plus emission standards

<i>Emission Reduction(TPD)</i>	NOx	PM
Statewide	2.2	0.22
South Coast	0.8	0.09
Rest of State	1.4	0.13

NOx:

NOx Baseline Emissions – $17.4 \text{ g/bhp-hr} \times 20.8 = 362 \text{ grams/gallon}$.

103 pre-Tier 0 UP and BNSF Switch Locomotives

$50,000 \text{ gallons/yr} \times 362 \text{ grams/gallon} = 18,100,000 \text{ grams/yr}$
 $18,100,000 \text{ grams/yr} / 454 \text{ g/lb} = 39,867.84 \text{ lbs/yr}$
 $39,867.84 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 19.93 \text{ tons/yr}$
 $19.93 \text{ tons/yr} / 365 \text{ days/yr} = 0.0546 \text{ tons/day}$
 $0.0546 \text{ tons/day} \times 103 \text{ pre-Tier 0 switchers} = 5.625 \text{ tons/day NOx emissions}$.

NOx Baseline Emissions – $14.0 \text{ g/bhp-hr} \times 20.8 = 291 \text{ grams/gallon}$.

49 Tier 0 UP and BNSF Switch Locomotives

$50,000 \text{ gallons/yr} \times 291 \text{ grams/gallon} = 14,550,000 \text{ grams/yr}$
 $14,550,000 \text{ grams/yr} / 454 \text{ g/lb} = 32,048.46 \text{ lbs/yr}$
 $32,048.46 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 16.0 \text{ tons/yr}$
 $16.0 \text{ tons/yr} / 365 \text{ days/yr} = 0.0439 \text{ tons/day}$
 $0.0439 \text{ tons/day} \times 49 \text{ Tier 0 switch locomotives} = 2.15 \text{ tons/day NOx emissions}$.

$103 \text{ pre-Tier 0 UP/BNSF switch locomotives} + 49 \text{ Tier 0 UP/BNSF switch locomotives} =$
 $(5.625 \text{ tons/day}) + (2.15 \text{ tons/day}) = 7.776 \text{ tons/day NOx or } 7.8 \text{ tons/day}$.

NOx baseline emissions for 152 older UP/BNSF switchers = 7.8 tons/day.

NOx Control Emissions – $11.8 \text{ g/bhp-hr} \times 20.8 = 245 \text{ grams/gallon}$.

152 Tier 0 Plus UP and BNSF Switch Locomotives

$50,000 \text{ gallons/year} \times 245 \text{ grams/gallon} = 12,250,000 \text{ grams/yr}$
 $12,250,000 \text{ grams/yr} / 454 \text{ g/lb} = 26,982.4 \text{ lbs/yr}$
 $26,982.4 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 13.49 \text{ tons/yr}$
 $13.49 \text{ tons/yr} / 365 \text{ days/yr} = 0.03696 \text{ tons/day}$
 $0.03696 \text{ tons/day} \times 152 \text{ Tier 0 Plus switch locomotives} = 5.618 \text{ tons/day}$
NOx controlled emissions or 5.6 tons/day NOx controlled.

NOx baseline emissions (7.776 tons/day) – NOx control emissions (5.618 tons/day) = 2.15775 tons/day
NOx reduced or 2.16 or **2.2 tons/day NOx reduced.**

PM:

PM Baseline Emissions – $0.72 \text{ g/bhp-hr} \times 20.8 = 15 \text{ grams/gallon}$.

152 pre-Tier 0 and Tier 0 UP and BNSF Switch Locomotives

$50,000 \text{ gallons/yr} \times 15 \text{ grams/gallon} = 750,000 \text{ grams/yr}$
 $750,000 \text{ grams/yr} / 454 \text{ g/lb} = 1,651.98 \text{ lbs/yr}$
 $1,651.98 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 0.826 \text{ tons/yr}$
 $0.826 \text{ tons/yr} / 365 \text{ days/yr} = 0.002263 \text{ tons/day}$
 $0.002263 \text{ tons/day} \times 152 \text{ pre-Tier and Tier 0 switchers} =$
0.344 tons/day PM baseline emissions.

PM Control Emissions – $0.26 \text{ g/bhp-hr} \times 20.8 = 5.408 \text{ or } 5.4 \text{ grams/gallon}$.

152 Tier 0 Plus UP and BNSF Switch Locomotives

$50,000 \text{ gallons/year} \times 5.4 \text{ grams/gallon} = 270,000 \text{ grams/yr}$
 $270,000 \text{ grams/yr} / 454 \text{ g/lb} = 594.7 \text{ lbs/yr}$
 $594.7 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 0.297 \text{ tons/yr}$
 $0.297 \text{ tons/yr} / 365 \text{ days/yr} = 0.0008147 \text{ tons/day}$
 $0.0008147 \text{ tons/day} \times 152 \text{ Tier 0 Plus} = 0.12383 \text{ tons/day PM controlled emissions or } \mathbf{0.12 \text{ tons/day PM controlled}}$.

PM baseline emissions (0.344 tons/day) – PM control emissions (0.12 tons/day) = 0.224 tons/day PM reduced or **0.22 tons/day PM reduced.**

Cost-effectiveness:

1 year: $(2.2+0.22) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (1 \text{ yr}) = 1,766,600 \text{ lbs/yr}$.

10 years: $(2.2+0.22) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (10 \text{ yrs}) = 17,666,000 \text{ lbs/10 yrs}$.

20 years: $(2.0+0.2) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (20 \text{ yrs}) = 35,332,000 \text{ lbs/20 yrs}$.

Capital costs: $\$250,000 / \times 152 \text{ locos} = \$38,000,000$.

Cost-effectiveness = $\$ (38,000,000 / 35,332,000)$ to $\$ (38,000,000 / 17,666,000)$

= $\$1.08/\text{lb}$ to $\$2.15/\text{lb}$ or $(\$1-2/\text{lb})$

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APPENDIX F:

Calculations for Medium Horsepower Locomotives

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PRELIMINARY DRAFT

Calculations of Tier 2b, Tier 4 , and Tier 0 Plus Locomotive NOx and PM Emissions:

(Source: EPA Fact Sheet – Emission Factors for Locomotives – EPA420-F-97-051 – December 1997)

<http://www.epa.gov/otaq/regs/nonroad/locomotv/frm/42097051.pdf>

Medium Horsepower Locomotive Emission Factors (EF)

<i>(g/bhp-hr)</i>	NOx EF	PM EF
Pre Tier 0	13.5	0.60
Tier 0	9.5	0.60
Tier 0+	8.0	0.22
Tier 2	4.0	0.10
Tier 4	1.3	0.03

Conversion Factors

<i>bhp-hr/gallon</i>
20.8

<i>tons/g</i>
1.10E-06

UP/BNSF/Passenger Medium Horsepower Locomotive Fleet Composition

<i>Medium HP</i>	# Locos	Pre-Tier 0
Statewide	400	400
South Coast	150	150
Rest of State	250	250

Other Key Assumptions:

All medium horsepower locomotives are assumed to consume 100,000 gallons of fuel per year.

PRELIMINARY DRAFT

Repower of 400 older Freight and Passenger MHP locomotives with new LEL engines:

<i>Emission Reduction(TPD)</i>	NOx	PM
Statewide	23	1.25
South Coast	8.6	0.47
Rest of State	14.4	0.78

NOx:

NOx Baseline Emissions – $13.5 \text{ g/bhp-hr} \times 20.8 = 281 \text{ grams/gallon}$.

360 UP/BNSF/Passenger Pre-Tier 0 MHP Locomotives

$100,000 \text{ gallons/yr} \times 281 \text{ grams/gallon} = 28,100,000 \text{ grams/yr}$
 $28,100,000 \text{ grams/yr} / 454 \text{ g/lb} = 61,894.27 \text{ lbs/yr}$
 $61,894.27 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 30.95 \text{ tons/yr}$
 $30.95 \text{ tons/yr} / 365 \text{ days/yr} = 0.08478 \text{ tons/day}$
NOx x 360 pre-Tier 0 MHP locomotives = 30.52 tons/day or
30.5 tons/day NOx baseline emissions.

NOx Baseline Emissions – $9.5 \text{ g/bhp-hr} \times 20.8 = 198 \text{ grams/gallon}$.

40 UP/BNSF/Passenger Tier 0 MHP Locomotives

$100,000 \text{ gallons/yr} \times 198 \text{ grams/gallon} = 19,800,000 \text{ grams/yr}$
 $19,800,000 \text{ grams/yr} / 454 \text{ g/lb} = 43,612.33 \text{ lbs/yr}$
 $43,612.33 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 21.81 \text{ tons/yr}$
 $21.81 \text{ tons/yr} / 365 \text{ days/yr} = 0.0597 \text{ tons/day}$
NOx x 40 Tier 0 MHP locomotives = 2.3897 tons/day or
2.4 tons/day NOx baseline emissions.

360 pre-Tier 0 UP/BNSF/Passenger MHP locomotives + 40 Tier 0 UP/BNSF/Passenger MHP locomotives =
 $(30.5 \text{ tons/day}) + (2.4 \text{ tons/day}) = \textbf{32.9 tons/day NOx baseline emissions for 400 older UP/BNSF/Passenger MHP Locomotives.}$

NOx Control Emissions – $4.0 \text{ g/bhp-hr} \times 20.8 = 83 \text{ grams/gallon}$.

400 UP/BNSF/Passenger MHP LEL Engine Repower Locomotives

$100,000 \text{ gallons/year} \times 83 \text{ grams/gallon} = 8,300,000 \text{ grams/yr}$
 $8,300,000 \text{ grams/yr} / 454 \text{ g/lb} = 18,281.94 \text{ lbs/yr}$
 $18,281.94 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 9.14 \text{ tons/yr}$
 $9.14 \text{ tons/yr} / 365 \text{ days/yr} = 0.025 \text{ tons/day}$
NOx x 400 MHP LEL Engine Repower Locomotives =
10.0175 tons/day **NOx controlled emissions or 10.0 tons/day NOx controlled.**

NOx baseline emissions (32.9 tons/day) – NOx control emissions (10.0 tons/day) =
22.9 or 23 tons/day NOx reduced.

PM:

PM Baseline Emissions – $0.6 \text{ g/bhp-hr} \times 20.8 = 12.5 \text{ grams/gallon}$.

400 pre-Tier 0 and Tier 0 UP/BNSF/Passenger MHP Locomotives

$100,000 \text{ gallons/yr} \times 12.5 \text{ grams/gallon} = 1,250,000 \text{ grams/yr}$
 $1,250,000 \text{ grams/yr} / 454 \text{ g/lb} = 2,753.3 \text{ lbs/yr}$
 $2,753.3 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 1.377 \text{ tons/yr}$
 $1.377 \text{ tons/yr} / 365 \text{ days/yr} = 0.00377 \text{ tons/day}$
PM x 400 pre-Tier and Tier 0 MHP Locomotives =
1.509 tons/day PM baseline emissions.

PM Control Emissions – $0.1 \text{ g/bhp-hr} \times 20.8 = 2 \text{ grams/gallon}$.

400 UP/BNSF/Passenger MHP Locomotives with LEL Engine Repowers

$100,000 \text{ gallons/year} \times 2 \text{ grams/gallon} = 200,000 \text{ grams/yr}$
 $200,000 \text{ grams/yr} / 454 \text{ g/lb} = 440.53 \text{ lbs/yr}$
 $440.53 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 0.22 \text{ tons/yr}$
 $0.22 \text{ tons/yr} / 365 \text{ days/yr} = 0.0006 \text{ tons/day}$
PM x 400 MHP Locomotives with LEL Engine Repowers = **0.241 tons/day PM controlled.**

PM baseline emissions (1.51 tons/day) – PM control emissions (0.24 tons/day) = 1.27 tons/day PM reduced or
1.25 tons/day PM reduced.

Cost-effectiveness:

1 year: $(23+1.25) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (1 \text{ yr}) = 17,702,500 \text{ lbs/yr}$.

10 years: $(23+1.25) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (10 \text{ yrs}) = 177,025,000 \text{ lbs/10 yrs}$.

20 years: $(23+1.25) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (20 \text{ yrs}) = 354,050,000 \text{ lbs/20 yrs}$.

Capital costs: $\$1,000,000 / 400 \text{ MHP LEL locomotives} = \$400,000,000$

Cost-effectiveness = $\$400,000,000 / 354,050,000 \text{ lbs/20 yrs}$ to $\$400,000,000 / 177,025,000 \text{ lbs/10 yrs}$

= $\$1.13/\text{lb}$ to $\$2.26/\text{lb}$ or **(\$1-2/lb)**

PRELIMINARY DRAFT

Replace up to 200 of the 400 older MHP locomotives with new MHP gen-set locomotives (*Complement and Alternative to MHP LEL Engine Repowers*)

Emission Reduction(TPD)	NOx	PM
Statewide	13.3	0.63
South Coast	6.65	0.315
Rest of State	6.65	0.315

NOx:

NOx Baseline Emissions – $13.5 \text{ g/bhp-hr} \times 20.8 = 281 \text{ grams/gallon}$.

200 UP/BNSF/Passenger Pre-Tier 0 MHP Locomotives

$100,000 \text{ gallons/yr} \times 281 \text{ grams/gallon} = 28,100,000 \text{ grams/yr}$
 $28,100,000 \text{ grams/yr} / 454 \text{ g/lb} = 61,894.27 \text{ lbs/yr}$
 $61,894.27 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 30.95 \text{ tons/yr}$
 $30.95 \text{ tons/yr} / 365 \text{ days/yr} = 0.084786676 \text{ tons/day}$
 $0.084786676 \text{ tons/day} \times 200 \text{ pre-Tier 0 MHP locomotives} = 16.957 \text{ tons/day}$
17 tons/day NOx baseline emissions.

NOx Control Emissions – $3.0 \text{ g/bhp-hr} \times 20.8 = 62 \text{ grams/gallon}$.

200 UP/BNSF/ MHP Gen-Set Replacement Locomotives

$100,000 \text{ gallons/year} \times 62 \text{ grams/gallon} = 6,200,000 \text{ grams/yr}$
 $6,200,000 \text{ grams/yr} / 454 \text{ g/lb} = 13,656.4 \text{ lbs/yr}$
 $13,656.4 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 6.83 \text{ tons/yr}$
 $6.83 \text{ tons/yr} / 365 \text{ days/yr} = 0.0187 \text{ tons/day}$
 $0.0187 \text{ tons/day} \times 200 \text{ MHP Gen-Set Locomotives} = 3.7415 \text{ tons/day}$
3.74 tons/day NOx controlled emissions.

NOx baseline emissions (17 tons/day) – NOx control emissions (3.74 tons/day) =
13.26 or 13.3 tons/day NOx reduced.

PM:

PM Baseline Emissions – $0.6 \text{ g/bhp-hr} \times 20.8 = 12.5 \text{ grams/gallon}$.

200 pre-Tier 0 and Tier 0 UP/BNSF/Passenger MHP Locomotives

$100,000 \text{ gallons/yr} \times 12.5 \text{ grams/gallon} = 1,250,000 \text{ grams/yr}$
 $1,250,000 \text{ grams/yr} / 454 \text{ g/lb} = 2,753.3 \text{ lbs/yr}$
 $2,753.3 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 1.377 \text{ tons/yr}$
 $1.377 \text{ tons/yr} / 365 \text{ days/yr} = 0.00377 \text{ tons/day}$
 $0.00377 \text{ tons/day} \times 200 \text{ pre-Tier and Tier 0 MHP Locomotives} = 0.754 \text{ tons/day}$
0.754 tons/day PM baseline emissions.

PM Control Emissions – $0.1 \text{ g/bhp-hr} \times 20.8 = 2 \text{ grams/gallon}$.

200 UP/BNSF/Passenger MHP Locomotives with Gen-Set Replacement Locomotives

$100,000 \text{ gallons/year} \times 2 \text{ grams/gallon} = 200,000 \text{ grams/yr}$
 $200,000 \text{ grams/yr} / 454 \text{ g/lb} = 440.53 \text{ lbs/yr}$
 $440.53 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 0.22 \text{ tons/yr}$
 $0.22 \text{ tons/yr} / 365 \text{ days/yr} = 0.0006 \text{ tons/day}$
 $0.0006 \text{ tons/day} \times 200 \text{ MHP Gen-Set Locomotives} = 0.12 \text{ tons/day}$
0.12 tons/day PM controlled.

PM baseline emissions (0.754 tons/day) – PM control emissions (0.12 tons/day) = 0.634 tons/day PM reduced or
0.63 tons/day PM reduced.

Cost-effectiveness:

1 year: $(13.3 + 0.63) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (1 \text{ yr}) = 10,168,900 \text{ lbs/yr}$.

10 years: $(13.3 + 0.63) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (10 \text{ yrs}) = 101,689,000 \text{ lbs/10 yrs}$.

20 years: $(13.3 + 0.63) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (20 \text{ yrs}) = 203,378,000 \text{ lbs/20 yrs}$.

Capital costs: $\$2,000,000 / \times 200 \text{ MHP LEL locomotives} = \$400,000,000$

Cost-effectiveness = $\$ (400,000,000 / 203,378,000 \text{ lbs/20 yrs})$ to $\$ (400,000,000 / 101,689,000 \text{ lbs/10 yrs})$

= $\$1.97/\text{lb}$ to $\$3.93/\text{lb}$ or **(\$2-4/lb)**

PRELIMINARY DRAFT

Remanufacture 400 older MHP locomotives to meet U.S. EPA Tier 0 Plus Emission Standards (*Less Expensive Alternative to LEL and Gen-Set Options*)

Emission Reduction(TPD)	NOx	PM
Statewide	13	1.0
South Coast	4.9	0.37
Rest of State	8.1	0.63

NOx:

NOx Baseline Emissions – $13.5 \text{ g/bhp-hr} \times 20.8 = 281 \text{ grams/gallon}$.

360 UP/BNSF/Passenger Pre-Tier 0 MHP Locomotives

$100,000 \text{ gallons/yr} \times 281 \text{ grams/gallon} = 28,100,000 \text{ grams/yr}$
 $28,100,000 \text{ grams/yr} / 454 \text{ g/lb} = 61,894.27 \text{ lbs/yr}$
 $61,894.27 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 30.95 \text{ tons/yr}$
 $30.95 \text{ tons/yr} / 365 \text{ days/yr} = 0.08478 \text{ tons/day}$
NOx x 360 pre-Tier 0 MHP locomotives = 30.52 tons/day or **30.5 tons/day** NOx baseline emissions.

NOx Baseline Emissions – $9.5 \text{ g/bhp-hr} \times 20.8 = 198 \text{ grams/gallon}$.

40 UP/BNSF/Passenger Tier 0 MHP Locomotives

$100,000 \text{ gallons/yr} \times 198 \text{ grams/gallon} = 19,800,000 \text{ grams/yr}$
 $19,800,000 \text{ grams/yr} / 454 \text{ g/lb} = 43,612.33 \text{ lbs/yr}$
 $43,612.33 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 21.81 \text{ tons/yr}$
 $21.81 \text{ tons/yr} / 365 \text{ days/yr} = 0.0597 \text{ tons/day}$
NOx x 40 Tier 0 MHP locomotives = 2.3897 tons/day or **2.4 tons/day** NOx baseline emissions.

360 pre-Tier 0 UP/BNSF/Passenger MHP locomotives + 40 Tier 0 UP/BNSF/Passenger MHP locomotives = $(30.5 \text{ tons/day}) + (2.4 \text{ tons/day}) = 32.9 \text{ tons/day}$

NOx baseline emissions for 400 older UP/BNSF/Passenger MHP Locomotives = 32.9 tons/day.

NOx Control Emissions – $8.0 \text{ g/bhp-hr} \times 20.8 = 166 \text{ grams/gallon}$.

400 UP/BNSF/Passenger MHP Locomotives Remanufactured to Tier 0 Plus NOx

$100,000 \text{ gallons/year} \times 166 \text{ grams/gallon} = 16,600,000 \text{ grams/yr}$
 $16,600,000 \text{ grams/yr} / 454 \text{ g/lb} = 36,563.87 \text{ lbs/yr}$
 $36,563.87 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 18.28 \text{ tons/yr}$
 $18.28 \text{ tons/yr} / 365 \text{ days/yr} = 0.05 \text{ tons/day}$
NOx x 400 MHP Locomotives Remanufactured to Tier 0 Plus NOx = 20.035 tons/day **or 20.0 tons/day NOx controlled emissions.**

NOx baseline emissions (32.9 tons/day) – NOx control emissions (20.0 tons/day) =

12.9 or 13 tons/day NOx reduced.

PM:

PM Baseline Emissions – $0.6 \text{ g/bhp-hr} \times 20.8 = 12.5 \text{ grams/gallon}$.

400 pre-Tier 0 and Tier 0 UP/BNSF/Passenger MHP Locomotives

$100,000 \text{ gallons/yr} \times 12.5 \text{ grams/gallon} = 1,250,000 \text{ grams/yr}$
 $1,250,000 \text{ grams/yr} / 454 \text{ g/lb} = 2,753.3 \text{ lbs/yr}$
 $2,753.3 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 1.377 \text{ tons/yr}$
 $1.377 \text{ tons/yr} / 365 \text{ days/yr} = 0.00377 \text{ tons/day}$
PM x 400 pre-Tier and Tier 0 MHP Locomotives = **1.509 or 1.51 tons/day PM baseline emissions.**

PM Control Emissions – $0.22 \text{ g/bhp-hr} \times 20.8 = 4.576 \text{ or } 4.6 \text{ grams/gallon}$.

400 UP/BNSF/Passenger MHP Locomotives Remanufactured to Tier 0 Plus PM Standards

$100,000 \text{ gallons/year} \times 4.6 \text{ grams/gallon} = 460,000 \text{ grams/yr}$
 $460,000 \text{ grams/yr} / 454 \text{ g/lb} = 1,013.21 \text{ lbs/yr}$
 $1,013.21 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 0.5066 \text{ tons/yr}$
 $0.5066 \text{ tons/yr} / 365 \text{ days/yr} = 0.001388 \text{ tons/day}$
PM x 400 MHP Locomotives Remanufactured to Tier 0 Plus Standards = **0.55518 tons per day or 0.555 tons per day PM controlled.**

PM baseline emissions (1.51 tons/day) – PM control emissions (0.555 tons/day) = 0.955 or 0.96 tons/day PM reduced or **1.0 tons/day PM reduced.**

Cost-effectiveness:

1 year: $(13+1.0) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (1 \text{ yr}) = 10,220,000 \text{ lbs/yr}$.

10 years: $(13+1.0) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (10 \text{ yrs}) = 102,200,000 \text{ lbs/10 yrs}$.

20 years: $(13+1.0) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (20 \text{ yrs}) = 204,400,000 \text{ lbs/20 yrs}$.

Capital costs: $\$250,000 / 400 \text{ MHP locomotives} = \$100,000,000$

Cost-effectiveness = $\$ (100,000,000 / 204,400,000 \text{ lbs/20 yrs})$ to $\$ (100,000,000 / 102,200,000 \text{ lbs/10 yrs})$

= $\$0.49/\text{lb}$ to $\$0.98/\text{lb}$ or **(\$0.5-1/lb)**

PRELIMINARY DRAFT

Retrofit 400 LEL or gen-set MHP locomotives with DPF and SCR

Emission Reduction(TPD)	NOx	PM
Statewide	6.8	0.18
South Coast	2.55	0.07
Rest of State	4.25	0.11

NOx:

NOx Baseline Emissions – $4.0 \text{ g/bhp-hr} \times 20.8 = 83.2 \text{ grams/gallon}$.

400 UP/BNSF/Passenger MHP LEL Engine Repower Locomotives

$100,000 \text{ gallons/year} \times 83.2 \text{ grams/gallon} = 8,320,000 \text{ grams/yr}/454 \text{ g/lb} = 18,325.99 \text{ lbs/yr}/2,000 \text{ lbs/ton} = 9.163$

$\text{tons/yr}/365 \text{ days/yr} = 0.0251 \text{ tons/day NOx} \times 400 \text{ MHP LEL Engine Repower Locomotives} =$

10.042 tons/day or **10.042 tons/day NOx baseline emissions.**

NOx Control Emissions – $1.3 \text{ g/bhp-hr} \times 20.8 = 27 \text{ grams/gallon}$.

400 UP/BNSF/Passenger MHP LEL Engine Repower Locomotives Retrofitted with SCR

$100,000 \text{ gallons/yr} \times 27 \text{ grams/gallon} = 2,700,000 \text{ grams/yr}/454 \text{ g/lb} = 5,947.17 \text{ lbs/yr}/2,000 \text{ lbs/ton} = 2.97 \text{ tons/yr}/365$

$\text{days/yr} = 0.0081468 \text{ tons/day NOx} \times 400 \text{ MHP LEL Engine Repowered Locomotives with SCR} = 3.2587 \text{ tons/day}$ or

3.26 tons/day NOx control emissions.

NOx baseline emissions (10.042 tons/day) – NOx control emissions (3.2583 tons/day) = 6.784 or

6.8 tons/day NOx reduced.

PM:

PM Baseline Emissions – $0.1 \text{ g/bhp-hr} \times 20.8 = 2.08 \text{ grams/gallon}$.

400 UP/BNSF/Passenger MHP Locomotives with LEL Engine Repowers

$100,000 \text{ gallons/year} \times 2.08 \text{ grams/gallon} = 208,000 \text{ grams/yr}/454 \text{ g/lb} = 458.15 \text{ lbs/yr}/2,000 \text{ lbs/ton} = 0.229 \text{ tons/yr}/365$

$\text{days/yr} = 0.0006276 \text{ tons/day PM} \times 400 \text{ MHP Locomotives with LEL Engine Repowers} =$

0.251 tons/day PM baseline emissions.

PM Control Emissions – $0.03 \text{ g/bhp-hr} \times 20.8 = 0.624 \text{ grams/gallon}$.

400 UP/BNSF/Passenger MHP Locomotives with LEL Engine Repowers Retrofitted with DPFs

$100,000 \text{ gallons/yr} \times 0.624 \text{ grams/gallon} = 62,400 \text{ grams/yr}/454 \text{ g/lb} = 137.45 \text{ lbs/yr}/2,000 \text{ lbs/ton} = 0.06872 \text{ tons/yr}/365$

$\text{days/yr} = 0.000188281 \text{ tons/day PM} \times 400 \text{ MHP Locomotives with LEL Engine Repowers and Retrofitted with DPFs}$

=0.0753 tons per day PM controlled emissions.

PM baseline emissions (0.251 tons/day) – PM control emissions (0.0753 tons/day) = 0.1757 tons/day PM reduced or

0.18 tons/day PM reduced.

Cost-effectiveness:

1 year: $(6.8+0.18) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (1 \text{ yr}) = 5,095,400 \text{ lbs/yr}$.

10 years: $(6.8+1.25) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (10 \text{ yrs}) = 50,954,000 \text{ lbs}/10 \text{ yrs}$.

20 years: $(6.8+1.25) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (20 \text{ yrs}) = 101,908,000 \text{ lbs}/20 \text{ yrs}$.

Capital costs: $\$500,000/ \times 400 \text{ MHP LEL locomotives retrofitted with SCR and DPF} = \$200,000,000$

Cost-effectiveness = $\$ (200,000,000/101,908,000 \text{ lbs}/20 \text{ yrs})$ to $\$ (200,000,000/50,954,000 \text{ lbs}/10 \text{ yrs})$

= $\$1.96/\text{lb}$ to $\$3.93/\text{lb}$ or **(\$2-4/lb)**

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APPENDIX G:

Calculations for Interstate Line Haul Locomotives

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PRELIMINARY DRAFT

Line Haul Locomotive Emission Factors (EF)

<i>(g/bhp-hr)</i>	NOx EF	PM EF
Tier 2	5.5	0.20
Tier 4	1.3	0.03

Conversion Factors

<i>bhp-hr/gallon</i>
20.8

<i>tons/g</i>
1.10E-06

Projected UP and BNSF Interstate Line Haul Locomotive Fleet Composition in 2020

<i>Interstate Line Hauls</i>	# Locos	Tier 2
Statewide	600	600
South Coast	300	300
Rest of State	300	300

Other Key Assumptions:

All line haul locomotives are assumed to consume 100,000 gallons of fuel per year. This assumes an interstate line haul locomotive consumes up to 500,000 gallons per year, traveling across county (e.g., Chicago to Los Angeles), and only 20 percent of annual consumption is within the state of California.

Assumes UP and BNSF interstate line haul locomotive fleet in California will be a Tier 2 fleet average by 2020. Net emissions reductions would be only difference between a Tier 2 and Tier 4 interstate line haul locomotive emissions (76% NOx and 85% PM).

PRELIMINARY DRAFT

Accelerate UP and BNSF national Tier 4 interstate line haul locomotive fleet with orders for up to 1,500 to ensure 600 operate in California on any given day:

Emission Reduction(TPD)	NOx	PM
Statewide	16	0.64
South Coast	8	0.32
Rest of State	8	0.32

NOx:

NOx Baseline Emissions – $5.5 \text{ g/bhp-hr} \times 20.8 = 114.4 \text{ grams/gallon}$.

600 UP and BNSF Tier 2 Interstate Line Haul Locomotives in 2020

$100,000 \text{ gallons/year} \times 114.4 \text{ grams/gallon} = 11,440,000 \text{ grams/yr}$
 $11,440,000 \text{ grams/yr} / 454 \text{ g/lb} = 25,198.24 \text{ lbs/yr}$
 $25,198.24 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 12.599 \text{ tons/yr}$
 $12.599 \text{ tons/yr} / 365 \text{ days/yr} = 0.034518 \text{ tons/day}$
NOx x 600 UP and BNSF Tier 2 Interstate Line Haul Locomotives = **20.71 tons/day** **or 20.7 tons/day NOx baseline emissions.**

NOx Control Emissions – $1.3 \text{ g/bhp-hr} \times 20.8 = 27 \text{ grams/gallon}$.

600 UP and BNSF Tier 4 Interstate Line Haul Locomotives in 2020

$100,000 \text{ gallons/yr} \times 27 \text{ grams/gallon} = 2,700,000 \text{ grams/yr}$
 $2,700,000 \text{ grams/yr} / 454 \text{ g/lb} = 5,947.17 \text{ lbs/yr}$
 $5,947.17 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 2.97 \text{ tons/yr}$
 $2.97 \text{ tons/yr} / 365 \text{ days/yr} = 0.0081468 \text{ tons/day}$
NOx x 600 UP and BNSF Tier 4 Interstate Line Haul Locomotives with SCR = **4.888 tons/day** **or 4.9 tons/day NOx controlled emissions.**

NOx baseline emissions (20.7 tons/day) – NOx control emissions (4.9 tons/day) = 15.8 or

16.0 tons/day NOx reduced.

PM:

PM Baseline Emissions – $0.2 \text{ g/bhp-hr} \times 20.8 = 4.16 \text{ grams/gallon}$.

600 UP and BNSF Tier 2 Interstate Line Haul Locomotives in 2020

$100,000 \text{ gallons/year} \times 4.16 \text{ grams/gallon} = 416,000 \text{ grams/yr}$
 $416,000 \text{ grams/yr} / 454 \text{ g/lb} = 916.3 \text{ lbs/yr}$
 $916.3 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 0.458 \text{ tons/yr}$
 $0.458 \text{ tons/yr} / 365 \text{ days/yr} = 0.0012552 \text{ tons/day}$
PM x 600 UP and BNSF Tier 2 Interstate Line Haul Locomotives in 2020 = **0.753 tons/day** **PM baseline emissions**

PM Control Emissions – $0.03 \text{ g/bhp-hr} \times 20.8 = 0.624 \text{ grams/gallon}$.

600 UP and BNSF Tier 4 Interstate Line Haul Locomotives in 2020

$100,000 \text{ gallons/yr} \times 0.624 \text{ grams/gallon} = 62,400 \text{ grams/yr}$
 $62,400 \text{ grams/yr} / 454 \text{ g/lb} = 137.45 \text{ lbs/yr}$
 $137.45 \text{ lbs/yr} / 2,000 \text{ lbs/ton} = 0.06872 \text{ tons/yr}$
 $0.06872 \text{ tons/yr} / 365 \text{ days/yr} = 0.000188281 \text{ tons/day}$
PM x 600 UP and BNSF Tier 4 Interstate Line Haul Locomotives with DPFs = **0.11297 tons or 0.113 per day** **PM controlled emissions.**

PM baseline emissions (0.753 tons/day) – PM control emissions (0.113 tons/day) = 0.64 or

0.6 tons/day PM reduced.

Cost-effectiveness:

1 year: $(16+0.6) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (1 \text{ yr}) = 12,118,000 \text{ lbs/yr}$.

10 years: $(16+0.6) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (10 \text{ yrs}) = 121,180,000 \text{ lbs/10 yrs}$.

20 years: $(16+0.6) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (20 \text{ yrs}) = 242,360,000 \text{ lbs/20 yrs}$.

30 years: $(16+0.6) \times (2,000 \text{ lbs/ton}) \times (365 \text{ days/yr}) \times (30 \text{ yrs}) = 363,540,000 \text{ lbs/30 yrs}$.

Capital costs: $\$3,000,000 / 1,500 \text{ UP and BNSF Tier 4 National Fleet Interstate Line Haul Locos} =$

$\$4,500,000,000$ (\$4.5 billion)

Cost-effectiveness = $\$ (4,500,000,000 / 363,540,000 \text{ lbs/30 yrs})$ to $\$ (4,500,000,000 / 121,180,000 \text{ lbs/10 yrs})$

= $\$12.38/\text{lb}$ to $\$37.13/\text{lb}$ or **(\$12-37/lb)**

APPENDIX H:
Calculations for Cargo Handling Equipment (CHE)

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PRELIMINARY DRAFT

Calculations of Cargo Handling Equipment NO_x and PM Emissions and Cost-Effectiveness

(Source: ARB Staff Report – Initial Statement of Reasons for Proposed Rulemaking – Regulation for Mobile Cargo Handling Equipment at Ports and Intermodal Rail Yards – October 2005
ARB Staff Report – Carl Moyer Program Guidelines – Part IV, Appendices – November 2005
CALSTART – LNG Yard Hostler Demonstration and Commercialization Project, Final Report - August 2008
Port of Los Angeles – Electric Truck Demonstration Project Fact Sheet – May 2008
National Renewable Energy Laboratory – “Using LNG as fuel in Heavy-Duty Tractors” – July, 1999)

LNG Yard Truck

Annual Baseline Emissions:

Yard Truck w/ 2007+ On-road Diesel Engine:

PM Emissions_{Baseline}:

$$[(0.01 \text{ g/bhp-hr} \times 170\text{hp} \times 0.39 \times 3,196 \text{ hr/yr}) \times (1 \text{ ton}/907,200\text{g})] = 0.002 \text{ ton/yr}$$

NO_x Emissions_{Baseline}:

$$[(0.27 \text{ g/bhp-hr} \times 170\text{hp} \times 0.39 \times 3,196 \text{ hr/yr}) \times (1 \text{ ton}/907,200\text{g})] = 0.06 \text{ ton/yr}$$

$$\text{Total Annual Baseline Emissions}_{PM + NO_x} = \underline{\underline{0.062 \text{ ton/yr}}}$$

8 Intermodal Railyards:

PM Emissions₂₀₀₅: 14.80 ton/yr

NO_x Emissions₂₀₀₅: 328 ton/yr

342.8 ton/yr

PM Emissions₂₀₁₀: 14.80 ton/yr \times 0.36 = 5.3 ton/yr

NO_x Emissions₂₀₁₀: 328 ton/yr \times 0.51 = 167 ton/yr

172.3 ton/yr

PM Emissions₂₀₁₅: 14.80 ton/yr \times 0.24 = 3.6 ton/yr

NO_x Emissions₂₀₁₅: 328 ton/yr \times 0.30 = 98.4 ton/yr

102 ton/yr

PM Emissions₂₀₂₀: 14.80 ton/yr \times 0.12 = 1.78 ton/yr

NO_x Emissions₂₀₂₀: 328 ton/yr \times 0.09 = 29.5 ton/yr

31.3 ton/yr

Annual Reduced Technology Emissions:

LNG Yard Truck:

PM Emissions_{reduced}:

N/A

NO_x Emissions_{reduced}:

$$[(2.68 \text{ g/bhp-hr} \times 170\text{hp} \times 0.39 \times 3196 \text{ hr/yr}) \times (1 \text{ ton}/907,200\text{g})] = 0.63 \text{ ton/yr}$$

$$\text{Total Annual Reduced Technology Emissions}_{PM + NO_x} = \underline{\underline{0.63 \text{ ton/yr}}}$$

8 Intermodal Railyards

PM Emissions₂₀₀₅: 0 ton/yr

NO_x Emissions₂₀₀₅: 202.9 ton/yr

PRELIMINARY DRAFT

*PM Emissions*₂₀₂₀: 0 ton/yr
*NOx Emissions*₂₀₂₀: 14.8 ton/yr

Annual Surplus Emission Reductions:

Total Annual Baseline Emissions_{PM + NOx} + Total Annual Reduced Technology Emissions_{PM + NOx}
0.062 ton/yr – 0.63 ton/yr = **-0.57 ton/year** (2007+ on-road engine)

Total Annual Baseline Emissions_{PM + NOx} + Total Annual Reduced Technology Emissions_{PM + NOx}
172.3 ton/yr – 202.9 ton/yr = **-30.3 ton/year** (2010 Railyard Emissions)

Total Annual Baseline Emissions_{PM + NOx} + Total Annual Reduced Technology Emissions_{PM + NOx}
101.6 ton/yr – 202.9 ton/yr = **-101.3 ton/year** (2015 Railyard Emissions)

Total Annual Baseline Emissions_{PM + NOx} + Total Annual Reduced Technology Emissions_{PM + NOx}
31.3 ton/yr – 202.9 ton/yr = **-171.6 ton/year** (2020 Railyard Emissions)

Cost Estimates:

LNG Yard Truck: \$120,000
8 Intermodal Railyards: \$120,000 x 322 = **\$38,640,000**

Cost Effectiveness: N/A

Electric Yard Truck:

Annual Baseline Emissions:

Yard Truck w/ 2007+ On-road Diesel Engine:

*PM Emissions*_{Baseline}:
[(0.01 g/bhp-hr x 170hp x 0.39 x 3,196 hr/yr) x (1 ton/907,200g)] = 0.002 ton/yr

*NOx Emissions*_{Baseline}:
[(0.27 g/bhp-hr x 170hp x 0.39 x 3,196 hr/yr) x (1 ton/907,200g)] = 0.06 ton/yr

*Total Annual Baseline Emissions*_{PM + NOx} = **0.062 ton/yr**

8 Intermodal Railyards:

*PM Emissions*₂₀₁₀: 14.80 ton/yr x 0.36 = 5.3 ton/yr
*NOx Emissions*₂₀₁₀: 328 ton/yr x 0.51 = 167 ton/yr
172.3 ton/yr

*PM Emissions*₂₀₁₅: 14.80 ton/yr x 0.24 = 3.6 ton/yr
*NOx Emissions*₂₀₁₅: 328 ton/yr x 0.30 = 98.4 ton/yr
102 ton/yr

*PM Emissions*₂₀₂₀: 14.80 ton/yr x 0.12 = 1.78 ton/yr
*NOx Emissions*₂₀₂₀: 328 ton/yr x 0.09 = 29.5 ton/yr
31.3 ton/yr

Annual Reduced Technology Emissions:

Electric Yard Truck:
*PM Emissions*_{reduced}:

PRELIMINARY DRAFT

N/A

NOx Emissions_{reduced}:

N/A

*Total Annual Reduced Technology Emissions_{PM + NOx} = **0 ton/yr***

8 Intermodal Railyards

PM Emissions₂₀₁₀: 0 ton/yr

NOx Emissions₂₀₁₀: 0 ton/yr

PM Emissions₂₀₁₅: 0 ton/yr

NOx Emissions₂₀₁₅: 0 ton/yr

PM Emissions₂₀₂₀: 0 ton/yr

NOx Emissions₂₀₂₀: 0 ton/yr

Annual Surplus Emission Reductions:

Total Annual Baseline Emissions_{PM + NOx} - Total Annual Reduced Technology Emissions_{PM + NOx}
0.062 ton/yr - 0 ton/yr = **0.062 ton/year** (2007+on-road engine)

Total Annual Baseline Emissions_{PM + NOx} - Total Annual Reduced Technology Emissions_{PM + NOx}
172.3 ton/yr - 0 ton/yr = **172.3 ton/year** (2010 Railyard Emissions)

Total Annual Baseline Emissions_{PM + NOx} - Total Annual Reduced Technology Emissions_{PM + NOx}
101.6 ton/yr - 0 ton/yr = **101.6 ton/year** (2015 Railyard Emissions)

Total Annual Baseline Emissions_{PM + NOx} - Total Annual Reduced Technology Emissions_{PM + NOx}
31.3 ton/yr - 0 ton/yr = **31.3 ton/year** (2020 Railyard Emissions)

Emission Benefit over 8 years:

(0.062 ton/yr x 8 years) x 2,000 lbs/ton = **992 lbs** (2007+on-road engine)

(172.3 tons/yr x 8 years) x 2,000 lbs/ton = **2,756,800 lbs** (8 Intermodal Railyards_{2010 Emissions})

(101.6 tons/yr x 8 years) x 2,000 lbs/ton = **1,625,600 lbs** (8 Intermodal Railyards_{2015 Emissions})

(31.3 tons/yr x 8 years) x 2,000 lbs/ton = **500,800 lbs** (8 Intermodal Railyards_{2020 Emissions})

Cost Estimates:

Electric Yard Truck: \$208,700

8 Intermodal Railyards: \$208,700 x 322 = \$67,201,400

Cost Effectiveness:

(\$208,700 ÷ 992 lbs) = **\$210/lb** (2007+on-road engine)

(\$67,201,400 ÷ 2,756,800 lbs) = **\$24.38/lb** (8 Intermodal Railyards_{2010 Emissions})

(\$67,201,400 ÷ 1,625,600 lbs) = **\$41.34/lb** (8 Intermodal Railyards_{2015 Emissions})

(\$67,201,400 ÷ 500,800 lbs) = **\$134.19/lb** (8 Intermodal Railyards_{2020 Emissions})

Energy Storage Systems:

Annual Baseline Emissions:

PRELIMINARY DRAFT

RTG Crane w/ Tier 4 Off-road Diesel Engine:

PM Emissions_{Baseline}:

$$[(0.01 \text{ g/bhp-hr} \times 300\text{hp} \times 0.43 \times 4,380 \text{ hr/yr}) \times (1 \text{ ton}/907,200\text{g})] = 0.006 \text{ ton/yr}$$

NOx Emissions_{Baseline}:

$$[(0.27 \text{ g/bhp-hr} \times 300\text{hp} \times 0.43 \times 4,380 \text{ hr/yr}) \times (1 \text{ ton}/907,200\text{g})] = 0.168 \text{ ton/yr}$$

$$\text{Total Annual Baseline Emissions}_{PM + NOx} = \underline{\underline{0.174 \text{ ton/yr}}}$$

8 Intermodal Railyards

PM Emissions₂₀₀₅: 4.95 ton/yr

NOx Emissions₂₀₀₅: 147.3 ton/yr

152.5 ton/yr

PM Emissions₂₀₁₀: 4.95 ton/yr $\times 0.58 = 2.9$ ton/yr

NOx Emissions₂₀₁₀: 147.3 ton/yr $\times 0.91 = 134$ ton/yr

136.9 ton/yr

PM Emissions₂₀₁₅: 4.95 ton/yr $\times 0.43 = 2.1$ ton/yr

NOx Emissions₂₀₁₅: 147.3 ton/yr $\times 0.79 = 116.4$ ton/yr

118.5 ton/yr

PM Emissions₂₀₂₀: 4.95 ton/yr $\times 0.43 = 1.45$ ton/yr

NOx Emissions₂₀₂₀: 147.3 ton/yr $\times 0.79 = 100.16$ ton/yr

101.6 ton/yr

Annual Reduced Technology Emissions:

Energy Storage System:

PM Emissions_{reduced}:

$$0.006 \text{ ton/yr} \times 0.25 = 0.0045 \text{ ton/yr}$$

NOx Emissions_{reduced}:

$$0.168 \text{ ton/yr} \times 0.25 = 0.126 \text{ ton/yr}$$

$$\text{Total Annual Reduced Technology Emissions}_{PM + NOx} = \underline{\underline{0.131 \text{ ton/yr}}}$$

8 Intermodal Railyards

PM Emissions₂₀₁₀: 2.9 ton/yr $\times 0.75 = 2.2$ ton/yr

NOx Emissions₂₀₁₀: 134 ton/yr $\times 0.75 = 100.5$ ton/yr

102.7 ton/yr

PM Emissions₂₀₁₅: 2.1 ton/yr $\times 0.75 = 1.6$ ton/yr

NOx Emissions₂₀₁₅: 116.4 ton/yr $\times 0.75 = 87.3$ ton/yr

88.9 ton/yr

PM Emissions₂₀₂₀: 1.45 ton/yr $\times 0.75 = 1.08$ ton/yr

NOx Emissions₂₀₂₀: 101.6 ton/yr $\times 0.75 = 76.2$ ton/yr

77.3 ton/yr

Annual Surplus Emission:

$$\text{Total Annual Baseline Emissions}_{PM + NOx} - \text{Total Annual Reduced Technology Emissions}_{PM + NOx} =$$

PRELIMINARY DRAFT

$0.174 \text{ ton/yr}_{\text{PM} + \text{NO}_x} - 0.131 \text{ ton/yr}_{\text{PM} + \text{NO}_x} = \underline{0.043 \text{ ton year}}$ (Tier 4 Off-road Diesel Engine)
 $136.9 \text{ ton/yr}_{\text{PM} + \text{NO}_x} - 102.7 \text{ ton/yr}_{\text{PM} + \text{NO}_x} = \underline{34.2 \text{ ton year}}$ (8 Intermodal Railyards_{2010 Emissions})
 $118.5 \text{ ton/yr}_{\text{PM} + \text{NO}_x} - 88.9 \text{ ton/yr}_{\text{PM} + \text{NO}_x} = \underline{29.6 \text{ ton year}}$ (8 Intermodal Railyards_{2015 Emissions})
 $101.6 \text{ ton/yr}_{\text{PM} + \text{NO}_x} - 77.3 \text{ ton/yr}_{\text{PM} + \text{NO}_x} = \underline{24.3 \text{ ton year}}$ (8 Intermodal Railyards_{2020 Emissions})

Emission Benefit over 20 years:

$(0.043 \text{ ton/yr} \times 20 \text{ years}) \times 2,000 \text{ lbs/ton} = \underline{1,720 \text{ lbs}}$ (Tier 4 Off-road engine)

$(34.2 \text{ tons/yr} \times 20 \text{ years}) \times 2,000 \text{ lbs/ton} = \underline{1,368,000 \text{ lbs}}$ (8 Intermodal Railyards_{2010 Emissions})

$(29.6 \text{ tons/yr} \times 20 \text{ years}) \times 2,000 \text{ lbs/ton} = \underline{1,184,000 \text{ lbs}}$ (8 Intermodal Railyards_{2015 Emissions})

$(24.3 \text{ tons/yr} \times 20 \text{ years}) \times 2,000 \text{ lbs/ton} = \underline{972,000 \text{ lbs}}$ (8 Intermodal Railyards_{2020 Emissions})

Cost Estimates:

Energy Storage System: \$160,000 - \$320,000

Eight Intermodal Railyards: \$10,720,000 - \$21,440,000

Cost Effectiveness:

$(\$160,000 \div 1,720 \text{ lbs}) = \underline{\$93.02/\text{lb}}$ (Tier 4 Off-road engine)

$(\$320,000 \div 1,720 \text{ lbs}) = \underline{\$186.05/\text{lb}}$ (Tier 4 Off-road engine)

$(\$10,720,000 \div 1,368,000 \text{ lbs}) = \underline{\$7.84/\text{lb}}$ (8 Intermodal Railyards_{2010 Emissions})

$(\$21,440,000 \div 1,368,000 \text{ lbs}) = \underline{\$15.67/\text{lb}}$ (8 Intermodal Railyards_{2010 Emissions})

$(\$10,720,000 \div 1,184,000 \text{ lbs}) = \underline{\$9.05/\text{lb}}$ (8 Intermodal Railyards_{2015 Emissions})

$(\$21,440,000 \div 1,184,000 \text{ lbs}) = \underline{\$18.11/\text{lb}}$ (8 Intermodal Railyards_{2015 Emissions})

$(\$10,720,000 \div 972,000 \text{ lbs}) = \underline{\$11.02/\text{lb}}$ (8 Intermodal Railyards_{2020 Emissions})

$(\$21,440,000 \div 972,000 \text{ lbs}) = \underline{\$22.06/\text{lb}}$ (8 Intermodal Railyards_{2020 Emissions})

Railyard Wide Span Gantry Cranes and Railyard Electrification:

Annual Baseline Emissions:

CHE Equipment at 8 intermodal Railyards:

*PM Emissions*₂₀₀₅: 25 tons/yr

*NOx Emissions*₂₀₀₅: 543 tons/yr

568 tons/yr

*PM Emissions*₂₀₁₀: 25 tons/yr x 0.48 = 12 tons/yr

*NOx Emissions*₂₀₁₀: 543 tons/yr x 0.65 = 353 tons/yr

365 tons/yr

*PM Emissions*₂₀₁₅: 25 tons/yr x 0.34 = 8.5 tons/yr

*NOx Emissions*₂₀₁₅: 543 tons/yr x 0.53 = 287.8 tons/yr

296.3 tons/yr

*PM Emissions*₂₀₂₀: 25 tons/yr x 0.2 = 5 tons/yr

*NOx Emissions*₂₀₂₀: 543 tons/yr x 0.2 = 108.6 tons/yr

113.6 ton/yr

Annual Reduced Technology Emissions:

PRELIMINARY DRAFT

WSG Crane at 8 intermodal Railyards:

PM Emissions_{reduced}:

N/A

NOx Emissions_{reduced}:

N/A

*Total Annual Reduced Technology Emissions_{PM + NOx} = **0 ton/yr***

Annual Surplus Emission:

Total Annual Baseline Emissions_{PM + NOx} + Total Annual Reduced Technology Emissions_{PM + NOx}

365 ton/yr – 0 ton/yr = **365 ton year** (2010 Emissions)
296.3 ton/yr – 0 ton/yr = **296.3 ton year** (2015 Emissions)
113.6 ton/yr – 0 ton/yr = **113.6 ton year** (2020 Emissions)

Emission Benefit over 20 years:

(365 tons/yr x 20 years) x 2,000 lbs/ton = **14,600,000 lbs** (8 Intermodal Railyards_{2010 Emissions})
(296.3 tons/yr x 20 years) x 2,000 lbs/ton = **11,852,000 lbs** (8 Intermodal Railyards_{2015 Emissions})
(113.6 tons/yr x 20 years) x 2,000 lbs/ton = **4,544,000 lbs** (8 Intermodal Railyards_{2020 Emissions})

Cost Estimates:

WSG Crane Installations at 8 intermodal Railyards: \$1,200,000,000

Cost Effectiveness:

(\$1,200,000,000 ÷ 14,600,000_lbs) = **\$82.19/lb** (8 Intermodal Railyards_{2010 Emissions})
(\$1,200,000,000 ÷ 11,852,000_lbs) = **\$101.25/lb** (8 Intermodal Railyards_{2015 Emissions})
(\$1,200,000,000 ÷ 4,544,000_lbs) = **\$264.08/lb** (8 Intermodal Railyards_{2020 Emissions})

APPENDIX I:

Calculations for Transport Refrigeration Unit (TRU) Plug In Electrification

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PRELIMINARY DRAFT

TRU PLUG-IN ELECTRIFICATION EMISSION CALCULATIONS:

PM Emission Reductions if installed at BNSF BNSF Hobart, BNSF San Bernardino, UP ICTF, UP Oakland, UP Commerce, UP City of Industry, UP LATC and BNSF Commerce Eastern assuming 100% mitigation:

PM Emission Reductions = Emissions x Emission Reduction Factor

PM Emission Reductions = 13.5 TPY x 0.08 = **1.08 TPY**

NOx Emission Reductions if installed at BNSF BNSF Hobart, BNSF San Bernardino, UP ICTF, UP Oakland, UP Commerce, UP City of Industry, UP LATC and BNSF Commerce Eastern assuming 100% mitigation:

NOx Emission Reduction = PM Emission Reductions * 10

NOx Emission Reduction = 1.08 TPY x 10 = **10.8 TPY**

PRELIMINARY DRAFT

COST-EFFECTIVENESS CALCULATIONS

TRU plug-in electrification Cost-Effectiveness Estimates

New reefer racks and associated electric infrastructure

Cost for reefer racks for 8 railyards= \$1,000,000 (\$1 million)

Cost for electric infrastructure for 8 railyards = \$500,000,000 (\$500 million)

Total Costs = \$501,000,000 (\$501 million)

(1) Cost-Effectiveness Calculation for New TRU plug-in electrification of 8 intermodal railyards

Cost for 8 New Reefer Racks and associated electric infrastructure \$ 1,000,000

$$\begin{aligned}\text{Cost Effectiveness (10 years)} &= \$501,000,000 / [(\text{NOx} + \text{PM} + \text{ROG}) \times 10 \text{ yrs}] \\ &= \$501,000,000 / [(10.8 \text{ ton/yr} + 1.08 \text{ ton/yr}) \times 2000 \text{ lb/ton} \\ &\quad \times 10 \text{ years}] \\ &= \mathbf{\$2,109/\text{lb}}\end{aligned}$$

PRELIMINARY DRAFT

References:

- (1) [Airborne Toxic Control Measure for In-Use Diesel-Fueled Transport Refrigeration Units \(TRU\) and TRU Generator Sets, and Facilities Where TRUs Operate](#) (2004 ARB)
- (2) Email Communication with Tim Leong at the Port of Oakland (2008)
- (3) [Railyard HRAs](#) (2008 ARB)
- (4) Intermodal Container Transfer Facility (ICTF) Modernization Project (2007 UP)
- (5) [Staff Report: Initial Statement of Reasons for Proposed Rulemaking: Airborne Toxic Control Measure for In-Use Diesel-Fueled Transport Refrigeration Units \(TRU\) and TRU Generator Sets, and Facilities Where TRUs Operate](#) (2003 ARB)

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APPENDIX J:

Calculations for Port and Intermodal Railyard Drayage Trucks

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PRELIMINARY DRAFT

LNG HD trucks

2007 HD truck NOx emission level = 5 g/mile

Average VMT = 40,000 miles/year

LNG HD truck NOx emissions compared to 2007 models = approximately 67%

NOx emission reduction from LNG HD trucks = (5 g/mile) x (40,000 miles/yr) X (1-67%)
= 146lb/yr

Capital cost = \$210,000/unit

Cost-effectiveness (15 years) = (\$210,000)/[(146lb/yr) x (15 years)] = \$96/lb

CNG HD trucks

2007 HD truck NOx emission level = 5 g/mile

Average VMT = 40,000 miles/year

CNG HD trucks NOx emissions compared to 2007 models = approximately 10%

NOx emission reduction from CNG HD trucks = (5 g/mile) x (40,000 miles/yr) X (1- 10%)
= 397 lb/yr

Capital cost = \$120,000/unit

Cost-effectiveness (15 years) = (\$120,000)/[(397 lb/yr) x (15 years)] = \$20/lb

PRELIMINARY DRAFT

Electric HD trucks

2007 HD truck NOx emission level = 5 g/mile

Average VMT = 40,000 miles/year

NOx reduction from electric HD trucks = (5 g/mile) x (40,000 miles/yr) X (100%)
= 441 lb/yr

Capital cost = \$210,000/unit

Cost-effectiveness (15 years) = (\$210,000)/[(441 lb/yr) x (15 years)] = \$32/lb

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APPENDIX K:

Calculations for Advanced Locomotive Emission Control System (ALECS)

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PRELIMINARY DRAFT

Cost-Effectiveness

DPM reduction from the UP Roseville maintenance facility = 1 ton/year (about 0.8 tpy)

NOx reduction (a factor of 20 from DPM reduction) = 20 ton/year

Capital cost = \$25,000,000

Cost-effectiveness (20 years) = (cost)/(emission reductions)
 = (\$25,000,000)/[(1+20)ton/yr x 2000lb/ton x 20 years]
 = \$30/lb

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PRELIMINARY DRAFT

Calculations for Total Diesel PM Emissions for Service and Maintenance Area for UP Roseville Railyard

PRELIMINARY DRAFT

TOTAL TPY FOR SERVICE AND MAINTENANCE FOR UP ROSEVILLE RAILYARD				
IDLING LOCOMOTIVES AT SERVICE TRACKS, MODSEARCH BUILDING, MAINTENANCE SHOP, AND READY TRACKS				
YARD LOCATION	ANNUAL NUMBER OF LOCOMOTIVES	DURATION OF EACH EVENT (mins)	ANNUAL AVERAGE HOURLY EMISSIONS RATE (g/hr)	ANNUAL DIESEL PM EMISSIONS (tpy)
Service Tracks				
Inspection pits	19,380.00	120.00	168.42	1.62
SUB-TOTAL	19,380.00	120.00	168.42	1.62
Modsearch Building				
Idling	7,200.00	120.00	15.67	0.15
SUB-TOTAL	7,200.00		15.67	0.15
Maintenance Shop				
East side Idling	5,400.00	120.00	47.02	0.454
West-side Idling	same as above	60.00	23.51	0.227
SUB-TOTAL	5,400.00		70.53	0.68
Ready Tracks				
Idling	21,547.49	120.00	148.15	1.43
SUB-TOTAL	21,547.49		148.15	1.43
GRAND-TOTAL				3.88
Source: UP Roseville Railyard Study (emission estimation baseline year 2000)				

PRELIMINARY DRAFT

MOVEMENT OF LOCOMOTIVES AT SERVICE TRACKS AND MAINTENANCE SHOP				
YARD LOCATION TO YARD LOCATION	ANNUAL NUMBER OF LOCOMOTIVES	DURATION OF EACH EVENT (mins)	ANNUAL AVERAGE HOURLY EMISSIONS RATE (g/hr)	ANNUAL DIESEL PM EMISSIONS (tpy)
SERVICE TRACKS Area				
In-bound to Wash Racks	19,380.49	5.00	10.3 - 14.4	0.10 - 0.14
Wash Racks to Service Trks	19,380.49	5.00	10.3 - 14.4	0.10 - 0.14
Service Trks to Ready Trks	14,251.47	5.00	7.54 - 10.60	0.073 - 0.102
Service Trks to Modsearch	7,200.00	15.00	8.13 - 12.80	0.08 - 0.12
SUB-TOTAL	19,380.49		36.27 - 52.2	0.35 - 0.50
AVERAGE TOTAL			44.24	0.43
Maintenance Shop Area				
Modsearch Buildings				
To East-side Maint. Shop	5,400.00	30.00	12.20 - 19.20	0.12 - 0.19
To Ready Tracks	1,800.00	10.00	1.35 - 2.13	0.013 - 0.021
Maintenance Shop				
West-side to Ready Tracks	5,400.00	10.00	4.06 - 6.40	0.039 - 0.062
SUB-TOTAL	5,400.00		17.61 - 27.73	0.039 - 0.062
GRAND-TOTAL	21,451.47		53.81 - 80.02	0.52 - 0.77
AVERAGE GRAND TOTAL			66.92	0.645
Source: UP Roseville Railyard Study (emission estimation baseline year 2000)				

PRELIMINARY DRAFT

LOCOMOTIVE TESTING AT SERVICE TRACKS, MODSEARCH BUILDING, AND MAINTENANCE SHOP				
YARD LOCATION	ANNUAL NUMBER OF TESTS	DURATION OF EACH EVENT (mins)	ANNUAL AVERAGE HOURLY EMISSIONS RATE (g/hr)	ANNUAL DIESEL PM EMISSIONS (tpy)
Service Tracks				
Pre-test emissions	1,354.00	*	19.47	0.19
Post test emissions	1,525.00	**	21.13	0.20
SUB-TOTAL	2,879.00		40.6	0.39
Modsearch Building				
Pre-test emissions	4,508.00	*	62.95	0.61
Post test emissions	none	**	none	none
SUB-TOTAL	4,508.00		62.95	0.61
Maintenance Shop				
East-side				
Pre-test emissions	799.00	*	9.25	0.089
Post test emissions	none	**	none	none
SUB-TOTAL	799.00		9.25	0.09
West-side				
Pre-test emissions	none	*	none	
Post test emissions	3,581.00	**	55.39	0.534
SUB-TOTAL	3,581.00		55.39	0.53
GRAND-TOTAL FOR TABLE 2.3	11,767.00			1.62
GRAND TOTAL FOR ALL TABLES			682.12	6.15 TPY
Grand total for Service and Testing is 6.15 tons per year according to Roseville Railyard study emissions estimation baseline year 2000.				

Note1- The length of the ready tracks is approximately 600 yards or 1800 feet.

The length of the of the inspection pit Area (part of the service track is) approximately 250 yards or about 750 feet.

The length of the Area on the east and west side of the maintenance shop is approximately 200 yards each side or about 600 feet.

Note 2-The emission estimation source is UP Roseville railyard Report.

Figures of UP Roseville Service and Maintenance Area

PRELIMINARY DRAFT

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PRELIMINARY DRAFT

Figure1-Aerial Picture of Roseville Railyard with Description of different Areas



Service Tracks

Modsearch Building

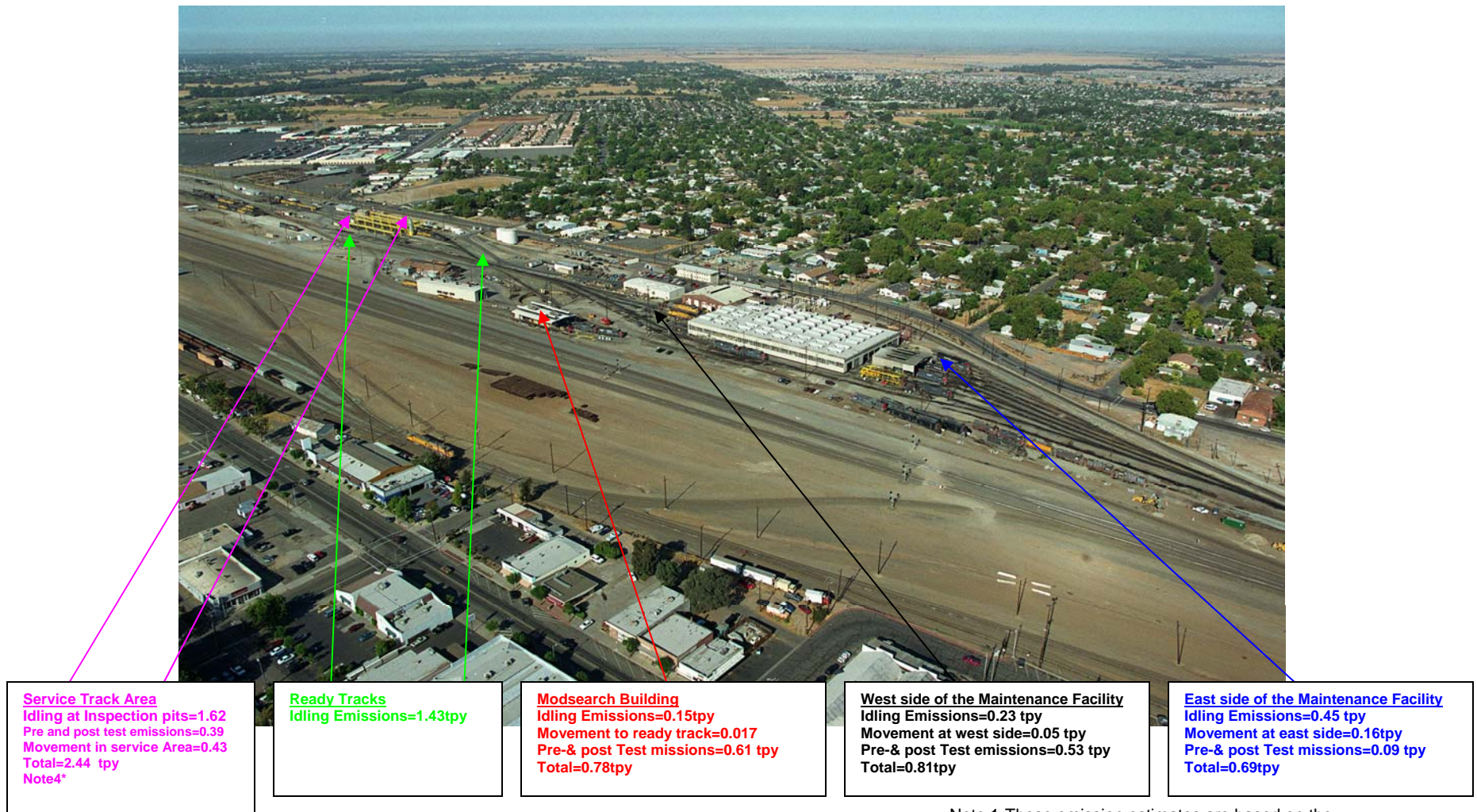
Ready Tracks

Maintenance
Shop

12/22/08

PRELIMINARY DRAFT

Figure 2: Descriptions of the Different Areas of the UP Roseville Railyard



emissions for baseline year 2000

Note 2- Service Track Emissions Occur over the whole length of the service tracks.

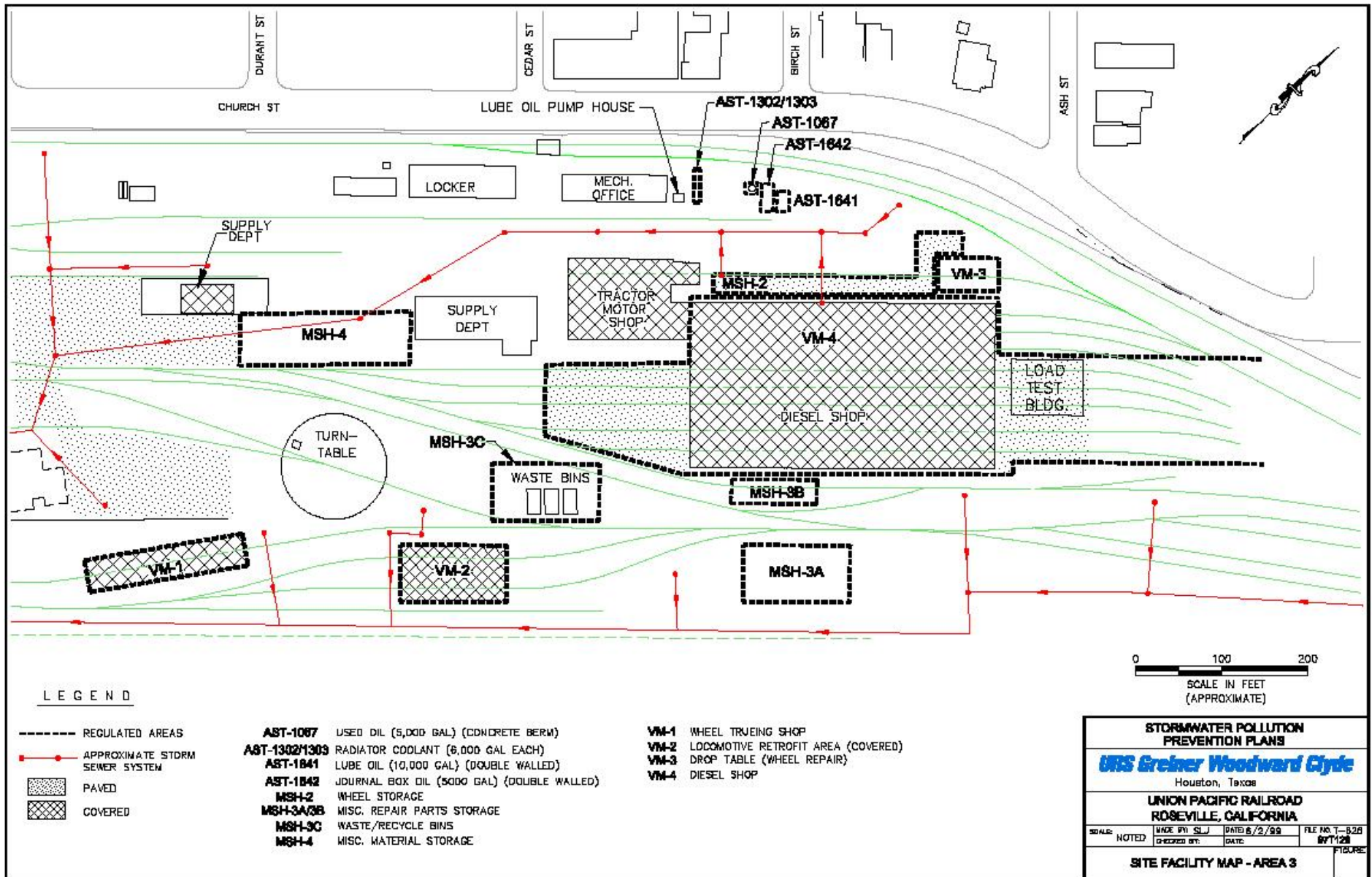
Note 3-Idling Emissions may have been significantly reduced since 2000 due to installation of Idle reduction Devices and Idling reduction requirements under the 2005ARB/Railroad MOU.

*Note 4=Movement in service Area emissions are further divided into 4 different areas as follows In-bound to Wash Racks=0.12tpy, Wash Racks to Service Trks=0.12tpy, Service Tracks to Ready Tracks=0.09tpy, Service Tracks to Modsearch=0.1tpy.

Note 1-These emission estimates are based on the

PRELIMINARY DRAFT

Figure1-Schematic Diagram of the Service and Maintenance Area of the UP Roseville Railyard.



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Pictures of Service and Maintenance Area for UP Roseville Railyard

PRELIMINARY DRAFT

Picture 1- Near-Source Picture of the Service Track Area as Shown in Figure 2



PRELIMINARY DRAFT

Picture 2-. Picture of the East Side of the Maintenance Shop as Mentioned in Figure 2.



PRELIMINARY DRAFT

Picture 3- Picture of the Service and maintenance area as shown in Figure 1.



PRELIMINARY DRAFT

Picture 4- Near- Source Picture of maintenance Area as Shown in Figure 1 and 2.



PRELIMINARY DRAFT

Picture 5- Near-Source Picture of East side of the Maintenance Area



PRELIMINARY DRAFT

Cost Element Definitions for Cost Effectiveness of ALECS

Cost elements are broken down into Initial Capital Costs, Operating and Maintenance Costs including Utility/Energy Costs, Repair and Replacement Costs, Downtime Costs, Environmental Costs, and Salvage Value.

A) Initial Capital Costs include engineering and design (drawings and regulatory issues), bidding process, purchase order administration, hardware capital costs, testing and inspection, inventory of spare parts, foundations (design, preparation, concrete and reinforcing), installation of equipment, connection of process piping, connection of electrical wiring and instrumentation, one-time licensing/permitting fees, and the start up (check out) costs.

B) Operating and Maintenance Costs include items such as labor costs of operators, inspections, insurance, warranties, recurring licensing/permitting fees, and all maintenance (corrective and preventive maintenance). Also included are yearly costs of consumables such as the utility/energy costs (electricity, natural gas, and water) and chemical costs (such as sodium hydroxide and urea).

C) Repair and Replacement Costs are the costs of repairing and replacing equipment over the life of the ALECS. This would also include catalyst material replacement.

D) Environmental Costs are associated with the disposal of wastewater, solid waste, used chemicals, and used parts.

E) The Salvage Value of the system would be the net worth of the ALECS in its final year of the life cycle period. If the system can be moved and salvaged for useful parts/purposes, there would be a reduction in life cycle costs.

F) Rail yard impact costs include estimates of costs incurred by the Union Pacific Railroad. An example would be if the ALECS was shut down for repairs and locomotives that normally would be serviced or stored in a specific area needed to be relocated and serviced/stored elsewhere. Rail yard impact costs would also include the costs to change rail yard operations that are different from what is practiced today (including structural changes, if needed, to accommodate ALECS). For example, the additional time and costs (including labor) of rerouting locomotives to the ALECS area if the locomotives may not have been normally required to be moved. Locomotive downtimes can be very expensive to the rail yard and may result in loss of revenue. Costs may also be negative (a benefit to the rail yard) if the implementation of ALECS produced increased efficiencies such as decreased dwell time (time a locomotive is in the rail yard). At the current time, Union Pacific Railroad does not have an estimate (positive or negative) as to the effect ALECS would have on rail yard operations. This cost is not included in the Analysis.

APPENDIX L:

**Calculations for Interstate Line Haul Locomotives
Operating with Idle Reduction Devices**

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PRELIMINARY DRAFT

Assuming on a conservative basis for a switch (yard) locomotive (assumed 10% idle reduction device benefits - some studies suggest up to 50% idle reduction benefits):

CONSERVATIVE CALCULATION OF IDLING REDUCTION EMISSION REDUCTION BENEFITS

KEY ASSUMPTIONS:

- Total Hours in a Calendar Year (365 x 24): 8,760 hours per year.
- Industry Standard for Locomotive Availability: 90 percent (10% maintenance/shutdown)
- Net Hours Locomotive Available Per Year 7,884 hours available per year.

SWITCH LOCOMOTIVES:

Average Hours Work Per Day:	15 hours/day
<u>Number of Days Available Per Year (90%)</u>	<u>329 day/year</u>
Annual Hours Worked Per Year	4,935 hours/year work
<u>U.S. EPA Duty Cycle – Idle Time (60%)</u>	<u>2,961 hours per year idle (~9 hours/day).</u>

Hours per year idle mode	2,961 hours/year
<u>Gallons per hour in idle mode</u>	<u>x 5 gallons/hour</u>
Gallons/Year Burned in Idle Mode	14,805 gallons/year
Idle Reduction Device	<u>10% idle reduction</u>
Gallons Diesel Fuel Unburned Due Idle Device	~1,500 gallons/year

NOx Emissions Calculations: 17.4 g/bhp-hr NOx (switch pre-Tier 0) x U.S. EPA bhp-hr conversion 20.8=362 grams/gallon.

~1,500 gallons/year x 362 grams/gallon = 543,000 grams/year/454 g/lb=**1,196.0 lbs/year**/2,000 lbs/ton=0.6 tons/year/365 days/year=0.0016 tons/day NOx reduced.

PM Emissions Calculations: 0.72 g/bhp-hr PM (switch pre-Tier 0) x U.S. EPA bhp-hr conversion 20.8=15 grams/gallon.

~1,500 gallons/year x 15 grams/gallon = 22,500 grams/year/454 g/lb=**49.6 lbs/year**/2,000 lbs/ton=0.025 tons/year/365 days/year=0.00007 tons/year PM reduced.

NOx (1,200 lbs/year) + PM (50 lbs/year) = 1,250 lbs/year of NOx and PM reduced.

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APPENDIX M:

Calculations to Electrify Major Freight Lines in the SCAB to Barstow and Niland

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PRELIMINARY DRAFT

FREIGHT ELECTRIFICATION EMISSION CALCULATIONS:

ARB Emission Inventory Projections 2010:

PM	TPY		TPD	
Source	2010	Electrification	2010	Elec
Main Line	252	0	0.69	0
Passenger	29	29	0.08	0.08
Switching	29	29	0.08	0.08
Total	310	58	0.85	0.16
				81%

NOx	TPY		TPD	
Source	2010	Electrification	2010	Elec
Main Line	5198	0	14.24	0
Passenger	949	949	2.6	2.6
Switching	1040	1040	2.85	2.85
Total	7187	1989	19.69	5.45
				72%

NOx Emissions in the SCAB:

Emissions = Total Emissions – Emissions from Main line Locos

Emissions = 19.69 TPD – 14.24 TPD = **5.45 TPD**

Diesel PM Emissions in the SCAB:

Emissions = Total Emissions – Emissions from Main line Locos

Emissions = 0.85 TPD – 0.69 TPD = **0.16 TPD**

PRELIMINARY DRAFT

COST EFFECTIVENESS CALCULATIONS:

Freight Electrification Cost Estimates:

ARB Analysis:

New Electric Freight Locomotive

Cost = approx \$8,000,000 (8 million)

Number of Locomotives = 775

Electric Retrofit of Existing Track

Cost = approx \$15,000,000/mile (15 million per mile)

Miles of Track = 460

Cost of Locomotives	$\$8,000,000/\text{loco} \times 775 \text{ locos} = \$6,200,000,000$
Cost of Track	$\$15,000,000/\text{mile} \times 460 \text{ miles} = \$6,900,000,000$
Total Cost	$\$6,200,000,000 + 6,900,000,000 = \$13,100,000,000$
Annualized Cost	$\$13,100,000,000 / 30 = \$436,666,667/\text{yr}$
Cost Effectiveness	$\$436,666,667/\text{yr} \div (\text{NOx} + \text{PM} + \text{ROG})$
	$\$436,666,667/\text{yr} \div [(5449)\text{ton}/\text{yr}]$
	= \$80,130/ton (30 years)
	= \$40/lb (30 years)

Note:

Cost Effectiveness assumes a project life of 30 years.

SCAG Analysis:

Renovation and purchase of electric locomotives:

Cost = approx \$6,400,000,000 (6.4 billion)

Total Cost	$\$6,400,000,000$
Annualized Cost	$\$6,400,000,000 / 30 = \$213,333,333/\text{yr}$
Cost Effectiveness	$\$213,333,333/\text{yr} \div (\text{NOx} + \text{PM} + \text{ROG})$
	$\$213,333,333/\text{yr} \div [(5449)\text{ton}/\text{yr}]$
	= \$39,148/ton (30 years)
	= \$20/lb (30 years)

Note:

Cost Effectiveness assumes a project life of 30 years.

PRELIMINARY DRAFT

References:

- (1) [ARB Emission Inventory](#) (2007 ARB)
- (2) [Caltrain Electrification Program Environmental Assessment/ Draft Environmental Impact Report](#) (2004 Peninsula Corridor Joint Powers Board)
- (3) [Final Program EIR/EIS for the Proposed California High-Speed Train System](#) (2005 California High Speed Rail Authority)
- (4) Freight Rail Emission Reduction Strategy to Help Meet 2014 Air Quality Standards for PM 2.5. (2007 SCAG)
- (5) Letter to SCAG from Kirk Markwald of The California Railroad Industry (2008 CRI)
- (6) Analysis of Good Movement Emission Reduction Strategies (2007 SCAG)
- (7) Comments on LA Times Article re Railway Electrification (2008 Mike Iden)

APPENDIX N:

Calculations for Maglev Electrification From the Port of LA/LB to ICTF/SCIG

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PRELIMINARY DRAFT

MAGLEV ELECTRIFICATION EMISSION CALCULATIONS:

Off Facility PM Emissions = Trips/day * Trip Length * # Facilities * grams DPM/mile * tons/g * 365 days/year

Off Facility PM Emissions = 6300 trips/day * 4.7 miles * 2 * 0.3 g/mile * 1.1x10⁻⁶ tons/g * 365 days/year = 7.1 TPY

On Facility PM Emissions = Emissions from ICTF * 2 Facilities

On Facility PM Emissions = 2.5 TPY * 2 = 5.0 TPY

Total PM Emissions = Off Facility Emissions + On Facility Emissions

Total PM Emissions = **12.1 TPY**

NOx Emissions = PM Emission * 20

NOx Emissions = 12.1 TPY * 20 = **242 TPY**

PRELIMINARY DRAFT

COST EFFECTIVENESS CALCULATIONS:

(1) Cost Effectiveness of Maglev Electrification (Low)

Installation of Maglev from Ports to ICTF/SCIG

Cost = approx \$65,000,000/mile (65 million)

Miles of Track = 4.7 miles

Cost	$\$65,000,000/\text{mile} \times 4.7 \text{ miles} = \$305,500,000$
Annualized Cost	$\$305,500,000 / 15 = \$20,366,667/\text{yr}$
Cost Effectiveness	$\$20,366,667/\text{yr} \div (\text{NOx} + \text{PM} + \text{ROG})$
	$\$20,366,667/\text{yr} \div [(242 + 12.1)\text{ton}/\text{yr}]$
	= \$79,934/ton (15 years)
	= \$40/lb (15 years)

Note:

Cost Effectiveness assumes a project life of 15 years.

(2) Cost Effectiveness of Maglev Electrification (High)

Installation of Maglev from Ports to ICTF/SCIG

Cost = approx \$170,000,000/mile (170 million)

Miles of Track = 4.7 miles

Cost	$\$170,000,000/\text{mile} \times 4.7 \text{ miles} = \$799,000,000$
Annualized Cost	$\$799,000,000 / 15 = \$53,266,667/\text{yr}$
Cost Effectiveness	$\$53,266,667/\text{yr} \div (\text{NOx} + \text{PM} + \text{ROG})$
	$\$53,266,667/\text{yr} \div [(12.1)\text{ton}/\text{yr}]$
	= \$209,058/ton (15 years)
	= \$105/lb (15 years)

Note:

Cost Effectiveness assumes a project life of 15 years.

PRELIMINARY DRAFT

References:

- (1) Shanghai Maglev Gets Official Approval (2006 China Daily)
- (2) Nagoya builds Maglev Metro (2004 International Railway Journal)
- (3) Intermodal Container Transfer Facility (ICTF) Modernization Project (2007 UPRR)
- (4) The Evaluation and Implementation Plan for Southern California Maglev Freight System (2007 CCDTT)
- (5) Proceedings of the Federal Transit Administrations Urban Maglev Workshop (2005 DOT)

Shanghai maglev gets official approval

By Miao Qing (China Daily)
Updated: 2006-04-27 06:11

After two years of operation, China's first magnetic levitation line has formally passed State examination and appraisal.

Yesterday's announcement augurs well for the proposed construction of a line connecting Shanghai and Hangzhou.

The existing line was started in March 2001 and completed 22 months later. The 30-kilometre track connects Shanghai's Pudong Airport with the city, and is largely based on German magnetic levitation (maglev) technology.

Maglev trains can travel at a speed of up to 430 kilometres per hour, whizzing passengers to their planes in less than eight minutes.

According to the National Development and Reform Commission (NDRC), which carried out the examination, the maglev trains had carried 6.23 million passengers by the end of March this year, both for transportation and sightseeing.

The cost of line was revealed to be 9.93 billion yuan (US\$1.2 billion), slightly below budget.

The successful construction and operation of the Shanghai maglev line is regarded by many as a good prelude to the construction of 175-kilometre line connecting Shanghai with Hangzhou, provincial capital of East China's Zhejiang Province.

Technology will remain a big concern in the construction of the new line, officials said. The Shanghai-Hangzhou maglev line will in part use German technology, but the State Council is encouraging engineers "to learn and absorb foreign advanced technologies while making further innovations."

Since accomplishing the first maglev line, China has mastered the core technology required to build maglev rail tracks, one of four major systems supporting the advanced mode of transportation, and gained 20 patents in the field.

"Lowering the cost of a maglev system is a significant issue in the study and construction of the Shanghai-Hangzhou maglev railway we are now confident we can achieve that," said Zhang Xiaoqiang, vice-minister of the NDRC.

"Our aim is to limit the cost of each kilometre of maglev line to approximately 200 million yuan (US\$24.6 million)." This means that the unit cost will be cut by one third.

The government also suggests the Shanghai maglev line operator could improve its operating management and efficiency, extend operation hours and attract more passengers.

APPENDIX O:

Calculations to Retrofit Existing Rail Infrastructure with LIMs in the SCAB

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PRELIMINARY DRAFT

RETROFIT OF EXISTING RAIL WITH LIMS EMISSION CALCULATIONS:

ARB Emission Inventory Data 2010:

PM			TPD	
Source	2010	Electrification	2010	Elec
Main Line	252	0	0.69	0
Passenger	29	29	0.08	0.08
Switching	29	29	0.08	0.08
Total	310	58	0.85	0.16
				81%

NOx			TPD	
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				72%

NOx Emissions in the SCAB:

Emissions = Total Emissions – Emissions from Main line Locos

Emissions = 19.69 TPD – 14.24 TPD = **5.45 TPD**

Diesel PM Emissions in the SCAB:

Emissions = Total Emissions – Emissions from Main line Locos

Emissions = 0.85 TPD – 0.69 TPD = **0.16 TPD**

PRELIMINARY DRAFT

COST EFFECTIVENESS CALCULATIONS

Retrofit of existing rail with LIMs

Cost / mile = \$16,000,000/mile

Miles of track = 460 miles

Cost to retrofit locomotives: \$3,000,000,000 (\$3 billion)

Track Cost	\$16,000,000/mile x 460 miles = \$7,360,000,000
Retrofit Cost	\$3,000,000,000
Total Cost	\$7,360,000,000 + \$3,000,000,000 = \$10,360,000,000
Annualized Cost	\$10,360,000,000 / 30 = \$345,333,333/yr
Cost Effectiveness	\$345,333,333/yr ÷ (NOx + PM))
	\$345,333,333/yr ÷ [(5198 + 252)ton/yr]
	= \$63,370/ton (30 years)
	= \$32/lb (30 years)

Note:

Cost Effectiveness assumes a project life of 30 years.

PRELIMINARY DRAFT

References:

- (1) Alternative Container Transportation Technology Evaluation and Comparison (2008 Ports of Long Beach and Los Angeles)
- (2) ARB Emission Inventory (2008 ARB)
- (3) Maglev and Linear Motors for Goods Movement (2007 SCAQMD)

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